Hand Book of Casinghead Gas

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4-23-24

HAND BOOK

OF

CASINGHEAD GAS

By

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THIRD EDITION

1922

PUBLISHED BY

METRIC METAL WORKS

ERIE, PENNSYLVANIA

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by
METRIC METAL WORKS
Erie, Pa.

Press of
ASHBY PRINTING CO.
Erie—Pittsburgh

PREFACE

The extraction of gasoline from Casinghead Gas has grown to be a business of importance. From its inception in 1900 to 1914, little progress was made, but since that time the industry has grown to be nearly equal to that of the Natural Gas Industry.

Since the publication of the Hand Book of Casinghead Gas in 1918, there have not been many radical changes in the method of extraction of gasoline from Casinghead Gas, but there have been many minor improvements.

In continuing the publication of this book the author is constantly endeavoring to condense such tables necessary to the work so as to permit the use of any new material brought out in the business. It has always been our aim to publish all the essential information on the subject in a book of convenient size for the man in the field.

We desire to thank personally Mr. John C. Diehl who has been closely associated with the author, together with many others who have in a large way assisted in furnishing the material.

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PART ONE

General

CASINGHEAD GASOLINE AND PRODUCTION

The production of casinghead gasoline has shown wonderful strides since its beginning in 1903. Little did such men as Sutton Bros. & Edmonds, William Richards or William Fassenmeyer realize how great the little industry that they started of "extracting" gasoline from casinghead gas, would eventually become.

Early in 1900 the foregoing men, and no doubt others, that to this day are still unknown but who were a factor in the beginning, started the casinghead gasoline business, which in 1920 exceeded $75,000,000* in gross sales of raw gasoline and which is still growing.

It is estimated that there are over 1,200 plants in operation in this country.

Prior to the above mentioned time, casinghead gas was either used for flambeau torches or was wasted into the atmosphere. Now and then one would find during the early period, instances where the gas was used for heating lease houses or to run gas engines.

During the first few years in which this business was gradually becoming established the market for gasoline was very unstable. Automobiles were considered a luxury, gasoline-propelled trucks were unheard of, the tractor and farm engines were unknown and the production of gasoline by refinery process was sufficient to readily take care of the normal requirements of the country.

Only a few years ago the price of gasoline was so low that the casinghead gasoline business received a severe setback. The oil refiners were able to depend upon the refining of lubricating oils, kerosene, naphtha and other

* In 1919 according to the Bureau of Mines the value of gasoline produced from Natural Gas and Casinghead Gas was $64,196,000.

Fig. 1—RENO GASOLINE PLANT AT SISTERSVILLE, WEST VIRGINIA

One of the First Installed

products of oil for profit and were not dependent entirely upon the production of gasoline when there was an over-production. On the other hand the casinghead gasoline producers were making one product and when the market was low or sluggish, due to over-production, the new industry was far from a profitable proposition. The writer can remember the time when a certain company in Oklahoma could find no market for its gasoline, and for several months, in order to hold their leases, they would move their daily production of gasoline to a safe distance from the plant, dump it on the ground and burn it. Their contracts called for their maintaining a vacuum on the wells and their storage tanks were filled to the utmost capacity so in order to keep their leases alive there was no other alternative than to burn the gasoline.

In 1912 the production of automobiles showed a wonderful increase, and the number of registered cars in the United States increased over 60 per cent. The number of registered automobiles and trucks increased from 667,000 in 1911 to 8,500,000 in 1920, or approximately 1300 per cent. This increased use of automobiles greatly stimulated the gasoline market both to the refiner as well as to the casinghead gas producer.

Without the latter industry and its wonderful production of gasoline annually the price of gasoline to the automobile owner would be considerably higher than it is to-day. There is no doubt that the production of gasoline by the refinery process, even with its increase from year to year, would not be of sufficient quantity to take care of the rapidly growing demand for gasoline for automobiles. Of course the production of gasoline by the refiner is dependent upon the oil production which itself has increased from year to year. Without the automobile, gasoline would be a drug in the market, and the casinghead gasoline producer would be unable to make a living.

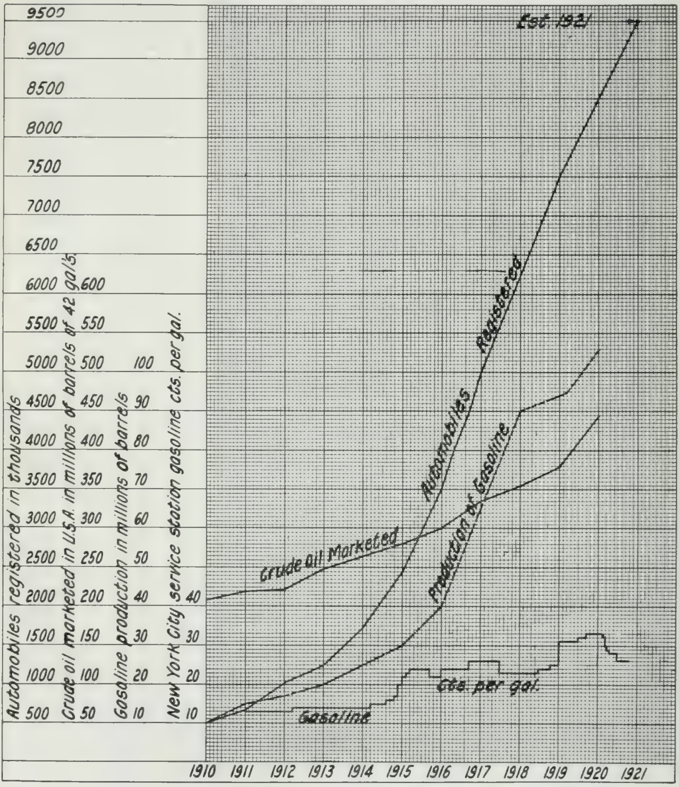


Fig. 2—CHART SHOWING THE INCREASE IN PRODUCTION OF OIL, GASOLINE AND AUTOMOBILES, TOGETHER WITH THE PRICE OF GASOLINE FROM 1910 TO 1921

It is interesting to note from the chart found on page 4 how the production of oil, gasoline and automobiles has increased during the past few years and how the price of gasoline has remained fairly stable in the same period. In other words, the natural conditions of the wonderful increase in production of our natural resources has kept pace with the increase in the manufacture of internal combustion engines of all types, creating a stable and even price market for gasoline during that period.

From 1912 to 1919 inclusive, the production of casinghead and absorption gasoline increased 8,000,000 barrels annually. During that same period the automobiles increased from 700,000 to 8,500,000.

Figuring 10 barrels of gasoline per year per car meant an increased demand for gasoline annually of approximately 78,000,000 barrels of gasoline.

The gasoline engine, farm tractor, motor boat, industrial uses such as by printers, and factories, cleaners, painters etc., are all either large or small factors in the consumption of gasoline.

While the aeroplane calls for high grade refinery gasoline the automobile is being gradually so constructed and improved that it is taking a lower gravity gasoline than ever before. A few years ago automobile users thought it necessary to purchase 68-72 gravity gasoline. At this writing the average gravity gasoline sold is approximately 60-62, and even lower. This fact has gradually tended to increase the supply of gasoline without taking into consideration the increase in the production of oil or casinghead and absorption gasoline.

CASINGHEAD GAS

Throughout this book the expression casinghead gas wells refers to oil wells flowing casinghead gas. They are distinct from a natural gas well as they do not supply gas alone but a combination of gas and oil. All oil wells do

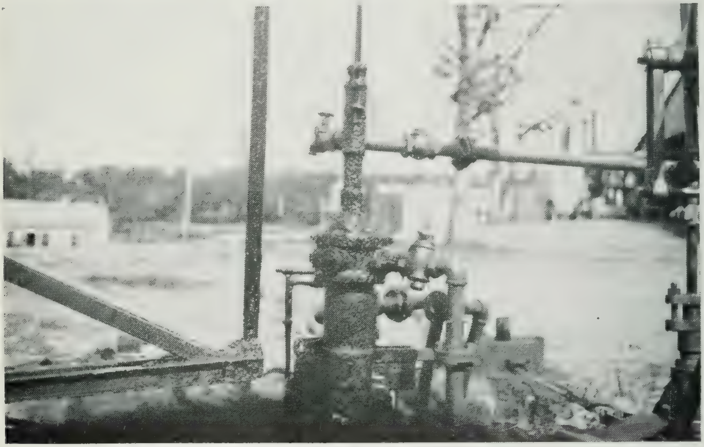


Fig. 3—PUMPING OIL WELL SHOWING CASINGHEAD AND LEAD LINES TO CARRY THE CASINGHEAD GAS TO THE VACUUM PUMP

not flow casinghead gas but some oil wells that have practically ceased flowing oil show a flow of casinghead gas which is worth conserving. Consequently, the author considers they are in a class by themselves distinct from either oil or natural gas wells.

A casinghead is the cast iron fitting that screws on the top of the casing of an oil well, through which the casinghead gas flows.

There are various sizes and designs of casingheads. Their size varies according to the casing, generally from 2¾ in. up to 10 in., and the opening in the top from one to four inches. The side openings vary from one to three inches,

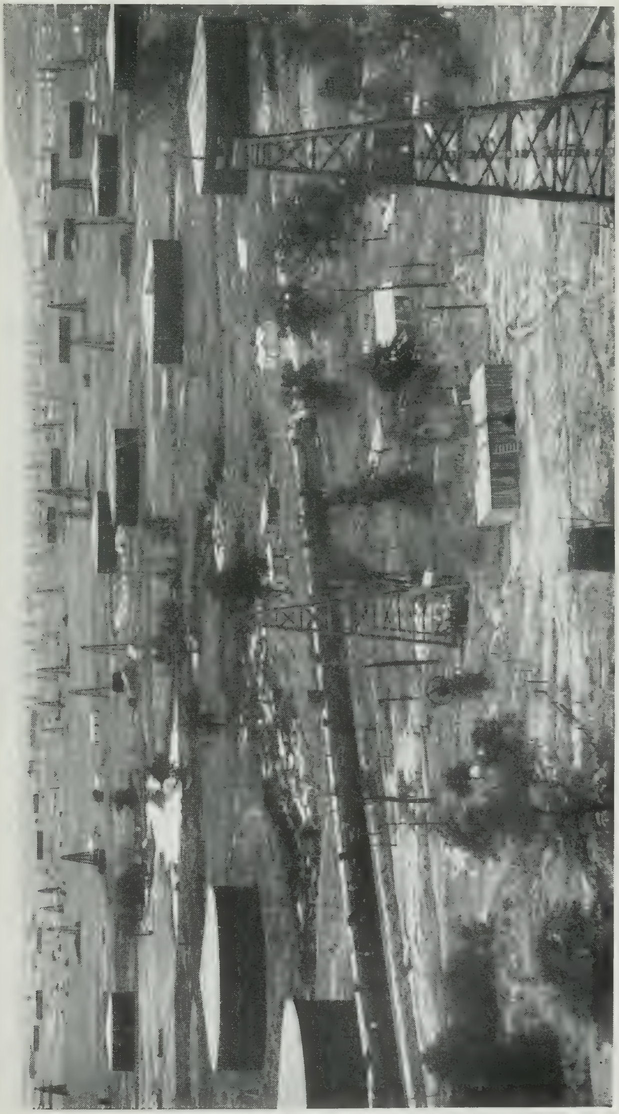


Fig. 4—GLENN POOL. Many Gasoline Plants can be seen in the distance

two inch being the most commonly used. The top is generally placed on top of a gasket and held in place by set screws through the casinghead. In the early days when the gas was not needed for local power, heating or flambeau torches, the side openings were left open and the casinghead gas flowed into the atmosphere.

Origin of Casinghead Gas*—"The several theories of the formation of petroleum are grouped in the three classes: (1) volcanic origin, (2) animal origin, (3) vegetable origin. Volcanic origin supposes that the action of volcanic gases on carbides in the hot portions of the earth's crust gives rise to the hydrocarbons; this theory has as its main support the formation of specific hydrocarbons in the laboratory experiments of the action of acids, water or steam on artificial carbides. Experiments such as the much cited distillations by Engler, show that tissues, especially fatty substances, may undergo destructive distillation and yield mixtures of hydrocarbons. The author has seen and examined one of Engler's products which was apparently very similar to petroleum of the type usually obtained from the Berea Grit Sand. The third theory, of vegetable origin, is based upon observations of the products of bacterial decomposition of plant tissues in marshes. This decomposition yields in addition to methane at least noticeable quantities of ethane. All evidence considered, the theory of animal origin seems to be the most plausible, though there is great probability that the other modes of formation played some part in the formation of our deposits of petroleum.

"Though there are several theories of the formation of petroleum, they all point to the usual formation of hydrocarbons of low molecular weight simultaneously with those of high molecular weight. That is, the whole series of hydrocarbons was formed together. Every evidence is that the gaseous hydrocarbons of low molecular weight, and the

*By O. J. Sieplein.

liquid and solid hydrocarbons of high molecular weight resulted from the same process or processes; in other words, natural gas and petroleum were of contemporaneous origin.

"These liquids would naturally vaporize and these gases would dissolve in the liquids. The tendency of liquids to vaporize decreases as the boiling point rises, and, other things being equal, the solubility of gases increases as the condensing point rises. In natural gas and petroleum, we have hydrocarbons boiling at temperatures ranging from —263 deg. fahr. to higher than 750 deg. fahr. For the present purpose we may limit our discussion to the paraffin hydrocarbons from methane (boiling point—263 deg.) to octane (boiling point 257 deg.). Of these hydrocarbons methane is the principal component of natural gas, while hexane, heptane and octane constitute refinery gasolines, butane and pentane occur in natural-gas gasoline, and propane and ethane compose the bulk of 'liquefied gas', such as 'Gasol.' The solubility of methane in petroleum was shown by Burrell to be about 15 per cent. The solubility of any gas is increased by increase of pressure. The amount of liquid vaporized depends only upon the temperature of the liquid and upon the free space above the liquid. From these considerations, it will be seen that as the pressure of natural gas above petroleum increases, the quantity of gas which dissolves in the petroleum will increase proportionately. Increase of pressure results in decrease of the total volume occupied by a given quantity of gas.

"Increased solution of the gas would result in a still further decrease of volume of gas above the petroleum, and thus of the space available for vapors. As a result of the decrease of volume occupied by gas there is a marked increase of the relative proportion of gas such as methane to vapor from the liquids, e. g., from pentane.

"In the case of high rock pressures propane and even ethane may be condensed to liquids and the result would be

that methane is the only true gas still present. The higher the rock pressure the lower is the quantity of the heavier hydrocarbons in the gas and the higher is the quantity of methane dissolved in the petroleum.

"Rock strata which are impervious to liquids such as petroleum are frequently not impervious to gases. A very thin layer of oil or water in the rock may easily seal it against the passage of oil or water. Even rocks which have been drained of their recoverable petroleum are known to contain large quantities of oil. The best evidence shows that the production of oil averages only 10 to 20 per cent of that actually contained in the sands. This retained oil may partially or even completely seal the sand to water. What is true of oil sealing sand to water is also true of water sealing sand to oil. When the hydrostatic pressure behind the oil in a sand has raised the pressure of the gas above the oil, this gas may be forced out of its original location through the pores of the overlying strata to some other location. Remaining in the oil-sand is a petroleum containing quite a large quantity of dissolved methane. When this reservoir is opened for production, pressure is released and some of the dissolved methane is released as a gas. Reduction of pressure causes ethane and propane, if present, to gasify, while vapors of butane, pentane, hexane, etc., are liberated to some extent. As the pressure of the well decreased, the proportion of methane to the higher members is continually declining. When gas pumps are placed on the wells to increase production of oil, this same effect is shown in a more marked degree.

"To summarize the question of the origin of casinghead gas: the ultimate origin is contemporaneous with the petroleum with which it is associated. The gas is essentially a mixture of natural gas and the vapors of the lighter components of petroleum. The proportion of vapor has been obviously increased by the loss of methane from the natural

storage reservoir in the earth. When the well is worked for petroleum, the coincident reduction of pressure on the petroleum permits the release of dissolved natural gas and vapors of petroleum in the form of the gaseous substance known as casinghead gas. The increased ratio of vapor in casinghead gas, which has been shown was brought about by natural processes, makes casinghead gas much better for production of natural-gasoline than is natural gas which has not gone through this natural enriching process."

Occurrence of Gasoline in Natural Gas.*—"When gas bubbles through or comes in contact with a liquid, it takes up and carries along vapor or minute particles of that liquid. The proportion of vapor that the gas can hold increases as the temperature rises, and is quite independent of the nature of the gas as long as no chemical action takes place. When natural gas in the earth comes in contact with petroleum, those fractions of the petroleum having the lower boiling points will be taken up first, as their vapor pressures are much higher than those of the other fractions. The vapors are carried with the gas in the same manner that water vapor exists with air. The amount of water vapor present in air is principally dependent upon the temperature of the air and the readiness with which the air can obtain the water. If the temperature of air saturated with water vapor be lowered, water vapor will deposit from the air, for air can hold only a certain quantity of water vapor at a particular temperature. Also, if a mixture of air and water vapor that is at a temperature below the critical temperature of water vapor is subjected to pressure, more water vapor can be condensed from the mixture by increasing the pressure. Also, if air containing water vapor be passed through a liquid that absorbs water vapor, it will be removed from the air.

* From Bulletin No. 120—Extraction of Gasoline from Natural Gas by Absorption Method, by Geo. A. Burrell, P. M. Biddison and G. G. Oberfell.

These statements hold true for natural gas that contains gasoline vapor. The gasoline can be removed by compression and condensation, as in the manufacture of casing-head gasoline, or by passing the natural gas through an oil that absorbs gasoline, as in the absorption method."

Natural Gas as Carrying Agent—Oil is composed of a large number of hydrocarbons with boiling points ranging from 32 deg. fahr. to 1000 deg. fahr.

The low boiling constituents of oil, when separated from others by distillation, compose the various grades of gasoline. Higher boiling portions constitute the various grades of burning oil, paraffin, etc.

Natural gas is the carrying agent—that is as it passes through or over oil in the sand or strata it picks up the lighter hydrocarbons, most of which can be separated from the natural gas by the absorption process or compressed to a high pressure and condensed.

When dry natural gas is passed over or through oil carrying gasoline, the latter will slowly vaporize or change into a gas when under the right temperature and pressure conditions until the gas becomes saturated with gasoline vapors. The lighter gasoline vapors would vaporize or change first.

This process is commonly spoken of as "the natural gas picking up the gasoline."

As the pressure of the gas or the oil is decreased the boiling points are lowered giving far greater vaporization action of the lighter hydrocarbons.

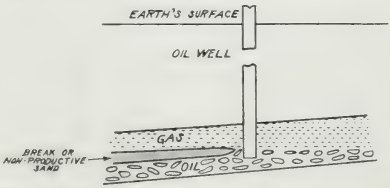


Fig. 5—ILLUSTRATION OF OIL SAND WHERE A BREAK EXISTS THROUGH PART OF THE SAND

If the gas followed the oil flowing through the sand to a certain pool or field for any great distance, it would pass over or through large quantities of oil lying in the sand and both the gas and the oil would be either high or low in gasoline content.

In Sistersville, W. Va., there are many small compression plants each working on the casinghead gas from one oil well. Actual tests show that the gravity of the oil has decreased as the vacuum on the wells increased. It must be borne in mind that, with few exceptions, the greater the vacuum on a casinghead gas well the greater the amount of gasoline obtainable.

In this instance a record of gasoline and oil production was carefully studied. It was found that the looser the sand or "pay" the greater the production of gasoline. When the vacuum was increased the gravity of the oil decreased, indicating that the gas was picking up more of the lighter hydrocarbons than it did under the smaller vacuum. This oil field gives as good an opportunity to study the effects of vacuum and pressure and effects of both on the oil as can be found. Evidently it is a good illustration of Fig. 6.

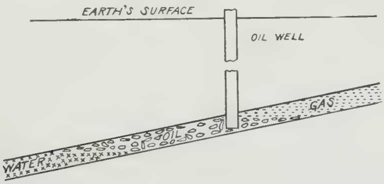


Fig. 6—OIL SAND WITH NO BREAK

If a large percentage of the gas picked up its gasoline vapors from some other distant pool, then in its travels encountered an oil pool carrying little or no gasoline vapors, which pool had been penetrated by the drill, this would account for instances where the casinghead gas was rich in gasoline but the oil showed but little.

In the Kiefer, Oklahoma, field when the pumping of an oil well is stopped, the oil raises in the well thereby decreasing vacuum or increasing the pressure on the sand, and the oil has a tendency to absorb some of the lighter hydrocarbons from the gas. The oil shows a higher gravity directly after a shut down than before. The explanation of this is, the oil raising in the well increases the pressure on the oil, and the latter absorbs some of the gasoline previously picked up by the gas. In this field the theory most applicable to the origin of the casinghead will be found in Fig. 7.

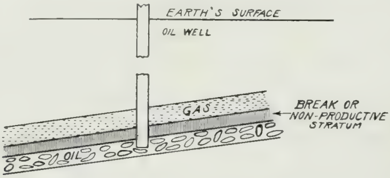


Fig. 7—OIL SAND WITH WELL DEFINED BREAK SEPARATING GAS SOIL

Because the casinghead gas from the Bartlesville sand in the Cushing field will yield approximately five gallons of gasoline per 1000 cubic feet of casinghead gas, it does not necessarily follow that this sand will prove as productive elsewhere.

Air as Carrying Agent*—"A promising field for the absorption process lies in the treatment of gas from oil wells where compressed air has been forced into some of the oil wells on a lease, for the purpose of increasing the production of oil from the other wells. The process consists of pumping compressed air into several wells on a lease, thus forcing more oil from that producing stratum into and out of other wells which are pumped than could otherwise be obtained. Old oil wells are treated by this method.

"Messrs. Smith & Dunn, of Marietta, Ohio, have successfully installed compressor plants at such wells in south-

* From Bulletin No. 120—Extraction of Gasoline from Natural Gas by Absorption Methods, by Geo. A. Burrell, P. M. Biddison and G. G. Oberfell.

eastern Ohio and northern Pennsylvania. On one property they report an increase from 4½ barrels to 32½ barrels per day; on another, from 22 to 70; and on a third, from 17 to 32.

The air in passing through the oil sands picks up and carries with it some of the lighter constituents of the oil, that is—gasoline.

Of course a certain amount of natural gas in the strata mixes with and emerges with the air and gasoline. The authors obtained information regarding the amount of gasoline carried by the mixtures as they flowed from different oil wells by collecting several samples and analyzing them. The results of three typical analyses are shown in the following table:

Table 1—ANALYSIS OF MIXTURES OF AIR AND NATURAL GAS FROM OIL WELLS

Constituent	Sample 1	Sample 2	Sample 3
	per cent	*per cent*	*per cent*
Carbon dioxide (CO_2)	0.20	0.70	1.00
Oxygen (O_2)	18.10	15.40	16.20
Natural Gas	7.20	10.60	12.80
Nitrogen (N_2)	74.50	73.30	70.00
Gasoline—pints per 1000 cu. ft. of gas.	4.60	7.30	5.90

Sample No. 1 represents about 135,000 cubic feet of gas. Sample No. 2 represents about 75,000 cubic feet of gas issuing from 12 wells. Sample No. 3 represents 25,000 cubic feet of gas from one well.

It will be observed that the gasoline content ranges from 4.6 to 7.3 pints per 1,000 cubic feet of gas.

Decrease of Pressure—It is a well known fact that as the pressure of natural gas wells decreases the amount of gasoline found in the gas increases, i. e. when the decrease in pressure is not due to water coming in on the gas sand but to the natural decline due to the age of the wells or field.

In one gas field in Clarion County, Pa., the specific gravity of the gas originally was about .644 while it now has increased to about .76 or greater. The rock pressure of this field has decreased from 900 lb. in 1902 to 80 lb. in 1918.

From a geological point of view there is nothing unusual in the many peculiarities found in casinghead gas when the gas is rich and the oil is "lean" in gasoline content, or where the gas is "lean" and the oil is rich in gasoline content.

As previously stated, the casinghead gas and the oil from one single well or one field should not be considered as necessarily having their source in or adjacent to either. The gas being more mobile of the two may travel miles before it comes in contact with the oil or may travel miles in conjunction with the oil before they are taken from a well.

One should consider that there seldom is any true regularity in either the structure, the thickness or the direction of an oil stratum. If one should study the general formation, structure, etc., of an exposed coal vein on an embankment for any distance, the peculiarities of nature would be far better understood. The vein or veins may thicken or divide into two or more veins, etc. Yet a coal vein is supposed to be one of the most regularly formed strata in the earth's crust. The oil and gas sands or strata are far more irregular than coal veins.

The law of vapor tension holds good in the oil sand in the earth's crust the same as on the surface. This is proven in the article given on page 15, which describes the results of pumping air into one oil well and taking it out of the others.

The fact that gas wells located in or near oil fields showed increasing gasoline content as the pressure decreased, is one of the most conclusive facts herewith presented.

It is very reasonable to believe that most gasoline vapors existing in casinghead gas were in this vaporous state and a part of the gas for a long period of time. While it is possible that part of the vapors were only recently picked up, especially where the casinghead gas wells are being operated, the major part of them no doubt assumed their vaporous state centuries ago. Of course, as the pressure is decreased on the wells, i. e., wells placed under vacuum by use of

Fig. 8—DRUMRIGHT REFINERY OF TIDAL REFINING COMPANY.
3,000 bbl. daily skimming capacity. Producing gasoline, naphtha, kerosene, gas oil and fuel oil without rerun stills. This plant is adjacent to natural gasoline plant for which it supplies blending material.

pumps, the boiling points of the hydrocarbons in the oil would be lowered and the percentage in vapor of the gas would naturally be increased.

Casinghead Gasoline Plant—Generally a gasoline plant or property consists of a number of oil leases grouped around a main compressor station in which the actual making of gasoline takes place. The gas lines from different wells on each lease run to a main line in which is placed a meter to measure the gas from that lease. The main line runs to the compressor station or plant.

The amount of gas necessary to make a profitable proposition is not only dependent upon the volume of gas but also on the quality of the gas. In other words a plant making six gallons of gasoline per thousand cubic feet from a volume of 100,000 cubic feet of gas per day is more profitable than a plant making but three gallons of gasoline per thousand cubic feet from a volume of 200,000 cubic feet of gas per day. The advantage is slight and arises from the fact that a smaller plant would be required for the smaller volume.

When there are scattered leases producing casinghead gas, booster stations, consisting of a small compressor, are located on the separate leases to assist in forcing the gas to the main plant where the gasoline is produced.

To further assist in the production, a vacuum pump or compressor is installed in the same building with the booster compressor. The object of the vacuum pump is to pump the gas from the wells and create a vacuum on them which materially increases the flow of the gas.

Vacuum has been placed on oil wells to increase the production even when the gas could not be used for making gasoline.

Casinghead gas is generally purchased at a few cents per thousand cubic feet, figured on a four ounce basis, settlements being made monthly. The price varies accord-

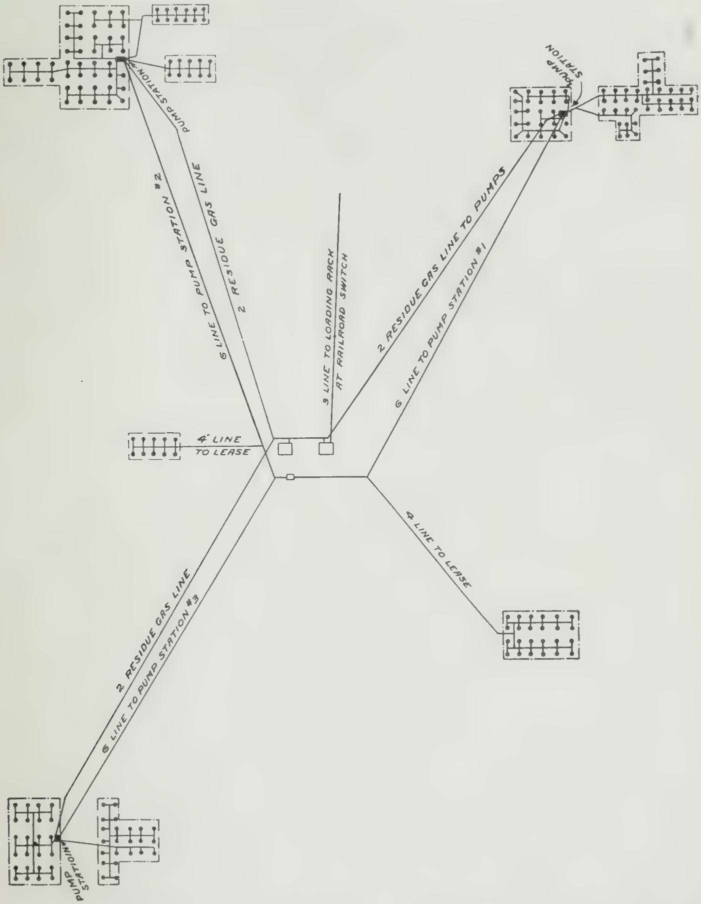


Fig. 9—GENERAL PLAN OF A GASOLINE PLANT
Showing Casinghead Gas and Residue Gas Lines to Various Groups of Leases

ing to the market price of gasoline. In some contracts the price of gas changes with the price of gasoline.

There are two processes of extracting gasoline. The one most commonly used is that by compression. The other is the absorption process, which is not only used with casing-head gas, but also with natural gas, commonly called "lean

gas," which carries as low as one-tenth of a gallon or less of gasoline per one thousand cubic feet. The absorption process is used with gas at high pressure as well as at low pressure.

In the compression process, the equipment consists of one or more two-stage compressors, coils, accumulating tanks, electric generator and other accessories.

The casinghead gas is compressed to a pressure of from fifty to three hundred pounds and then passed through a system of coils on which cold water is constantly dripping. This cools the gas, condensing the gasoline from it, the liquid being separated into respective accumulating tanks and the residue gas passing off to be used for power or heating purposes.

After the gasoline is collected in the accumulating tanks, it passes into blending-tanks, where it is blended with naphtha or other blending mediums to lower the gravity so as to permit of shipping without severe loss through evaporation and to make the shipping of it a safe matter.

The absorption process is a method of passing the gas through oil and separating the gasoline vapor from it by absorption of gasoline into the oil. There are two general designs in absorption plants one of which uses the horizontal absorbers and the other the vertical absorbers. The former requires mainly a series of large size pipes or tanks capable of holding high pressure, in which are placed small pipes carrying a large number of small holes, generally 1-16 of an inch in diameter. The tanks or pipes are partially filled with an oil heavier than gasoline, from which the lighter hydrocarbons have previously been extracted, and the gas is turned into the tanks or pipes through the small perforated lines. The gas flowing from the small perforations comes in contact with the oil and intimately mixes with the oil as it passes through it. The absorption of gasoline from the gas takes place as the oil and gas come together. The

oil is then run off and distilled by steam distillation in the same manner as at an oil refinery.

The vertical or tower system, consists of a series of high pressure pipes often as large as 36 inches in diameter, vertically installed, with the gas entering at the bottom and discharging at the top and the oil entering the top of the towers and being formed into a spray by baffle plates or stone work, it drops gradually to the bottom of the tower where it is drawn off and pumped to a still where the gasoline is distilled from it.

With either system the oil is used over and over again.

History—While a few isolated instances are known where gasoline was condensed from high pressure natural gas, it was not until 1903 that the collection of gasoline from casinghead gas, and the sale of it, became an established business. In that year, across the Ohio River from Sistersville, West Virginia, were located several oil wells flowing casinghead gas. This gas was used under boilers often three or four miles distant. A steam pump at the wells was used to force the gas to the point of consumption.

It was soon discovered that the gas lines were showing considerable quantities of gasoline, especially in the low spots or sags, which led to the installation of common pipe drips along the lines. From this came the use of a system of coils placed in old boilers or tanks filled with running water. The gasoline was collected daily in wooden barrels, hauled to the river and shipped to Parkersburg, where a ready market was found.

The gasoline ran about 70 degrees Baume.

To the writer's knowledge, the first ones to establish the business of collection and sale of gasoline from casinghead gas were Sutton Bros. & Edmonds, of Sistersville, W. Va. Later on, regular vacuum pumps were installed at the casinghead gas wells for pumping gas to increase the gas supply, and compressors to assist in forcing the gas to

Fig. 10—GASOLINE PLANT AT KIEFER, OKLA.

the boilers at distant points. It was soon noted by the installation of the foregoing that the yield of gasoline was considerably increased.

In the year 1905, the first known plant especially built for extracting gasoline by the compression method was installed by William Richards, at Mayburg, Pennsylvania.

From this and the small beginning in 1903, but eighteen years ago, this industry has grown and broadened until now there are many hundreds of plants scattered from the eastern oil fields to the Pacific coast producing, in 1920 approximately seventy-five million dollars' worth of gasoline.

Natural-Gas Gasoline Produced in the United States in 1919*—The natural-gas gasoline industry continued its rapid expansion in 1919, according to E. G. Sievers, of the United States Geological Survey, Department of the Interior. The output during the year was 351,535,026 gallons, an increase of 24 per cent over that in 1918. In 1919 the compression plants, which have been the largest producers since the beginning of the industry, made an output of 261,157,587 gallons. This output was 74 per cent of the total quantity produced during the year and an increase of 19 per cent over that produced by the compression method in 1918. The absorption process contributed 90,377,439 gallons or 26 per cent of the total output, which was 44 per cent more than it contributed in 1918. The average daily production in 1919 was 963,110 gallons as compared with 774,070 gallons in 1918.

The total output of gasoline in the United States in 1919 was 4,185,207,321 gallons. Of this quantity 3,833,672,295 gallons, or 92 per cent, was straight-run gasoline distilled from crude petroleum, and the rest was produced from natural gas.

The market value of the total natural-gas gasoline in 1919 was $64,196,763, an increase of $13,833,228. The value of the compression gasoline was $45,563,458 and that

* U. S. Geological Survey.

of the absorption gasoline was $18,633,305, amounts 21 and 47 per cent larger, respectively, than those for 1918. The average price received for the total output of natural-gas gasoline at the point of production in 1919 was 18.2 cents a gallon; the average price received in 1918 was 17.8 cents a gallon. The average price of the gasoline produced by the compression plants and vacuum pumps in 1919 was 17.4 cents a gallon, as compared with 17.1 cents in 1918, and that of the output recovered at the absorption plants or salvaged as drip from the mains was 20.5 cents a gallon, as compared with 20.3 cents in 1918.

The average yield of gasoline per 1,000 cubic feet of gas increased in 1919 to 0.74 gallon and was 0.11 gallon greater than in 1918. The total volume of natural gas treated in 1919 was 480,403,963,000 cubic feet, or 31,295,300,000 cubic feet more than in 1918. Of this total quantity 117,669,332,000 cubic feet were treated at the compression plants and 374,928,966,000 cubic feet at the absorption plants. The yield per thousand cubic feet of the day gas is less than that of the wet gas, a fact that accounts for the smaller production of the absorption plants from a larger volume of gas treated.

The construction of plants was also stimulated in 1919. At the end of the year there were 1,191 plants, an increase of 187 over 1918. The compression plants increased by 160 and the absorption plants by 27. In 1919 natural-gas gasoline was made by 611 operators; in 1918 by 503.

In 1919 every producing State increased its output except Colorado, which ceased producing entirely. The producing States, listed in the order of percentage of increase over 1918, are as follows: Wyoming, 253; New York, 110; Kentucky, 54; Louisiana, 43; West Virginia, 39; Kansas,37; Illinois, 32; Ohio, 31; Pennsylvania, 29; Texas, 27; California 25; Oklahoma, 16.

The following tables show in detail the progress of the natural-gas gasoline industry.

Table 2—STATISTICS OF CASINGHEAD GASOLINE IN U. S. 1911—1919*

Year	Number of Operators	Plants: Number of Plants	Plants: Daily Capacity Gallons	Gasoline Produced: Quantity Thousand Gallons	Gasoline Produced: Value	Price per Gallon Cents	Gas used: Estimated Volume Million cu. ft.	Value *a*	Av. yield gallons per M. cu. ft.
1911	132	176	37,100	7,425	$531,704	7.16	2,476	176,961	3.00
1912	186	250	61,268	12,081	1,157,476	9.60	4,688	331,985	2.60
1913	232	341	152,415	24,060	2,458,443	10.22	9,889	566,224	2.43
1914	254	386	179,353	42,652	3,105,909	7.28	16,895	889,906	2.43
1915	287	414	232,336	65,364	5,150,823	7.88	24,064	1,202,555	2.57
1916 Compression	460	550	375,565	84,922	11,493,701	13.53	36,713	*b* 14,609,351	2.32
1916 Absorption		46	119,883	18,569	2,837,447	15.28	171,992		.108
1917 Compression	750	784	671,502	168,866	30,596,930	18.12	79,528	*b* 34,343,024	2.12
1917 Absorption		102	230,883	49,017	9,592,026	19.57	349,760		.140
1918	*c*503	1004		282,535	50,363,535	17.80	449,108	*b*40,419,779	.63
1919	*c*611	1191		351,535	64,196,763	18.20	480,403	*b*41,314,740	.74

* From statistics compiled by the Bureau of Mines.

a The value of the gas is based on sales to gasoline producers, not on sales for domestic or industrial purposes. *b* Estimated. *c* The number of operators in 1918 and 1919 is not comparable with that for earlier years as the method of listing has been changed.

Table 3—UNBLENDED NATURAL GAS GASOLINE PRODUCED IN THE UNITED STATES IN 1919

State	Number of Operators	Number of Plants	Gasoline Produced			Gas Used		Percentage of total Production of State		Percentage of total Production of United States		
			Quantity Thousands of gallons	Value Thousands	Average price cents	Estimated Volume Mil. Cu. Ft.	Average yield gallon	Compression	Absorption	Compression	Absorption	Total
Oklahoma	161	329	189,995	$32,564	17.1	100,776	1.86	92.5	7.5	67.31	15.7	54.0
West Virginia	89	227	52,150	12,179	23.3	167,239	.31	30.3	69.7	6.05	40.2	14.8
California	30	60	40,385	5,744	14.2	39,647	.79	73.0	27.0	11.29	12.1	11.5
Pennsylvania	241	343	20,283	4,407	21.7	56,280	.35	57.6	42.4	4.47	9.5	5.8
Louisiana	12	23	10,063	1,667	16.5	26,383	.34	63.6	36.4	2.45	4.1	2.9
Texas	15	24	9,336	1,772	18.9	8,732	1.06	70.8	29.2	2.53	3.0	2.7
Ohio	35	59	8,800	1,963	22.3	43,609	.20	26.9	73.1	.91	7.1	2.5
Illinois	42	93	6,059	1,115	18.4	3,160	1.91	100.0	....	2.32	....	1.7
Wyoming	3	5	5,580	931	16.7	3,687	1.51	89.2	10.8	1.91	.7	1.6
Kentucky	7	9	5,136	1,144	22.3	20,216	.25	2.9	97.1	.06	5.5	1.5
Kansas	10	13	3,282	620	18.9	10,432	.31	42.1	57.9	.53	2.1	.9
New York	6	6	457	84	18.3	237	1.93	100.0	....	.17	....	.1
Total, 1919	*a*611	1191	*b*351,535	64,196	18.2	480,403	.74	74.3	25.7	100.00	100.00	100.00
Total, 1918	*a*553	1004	282,535	50,363	17.8	449,108	.63	77.8	22.2	100.00	100.00	100.00

a The number of operators in 1918 and 1919 is not comparable with that for earlier years as the method of listing has been changed.

b Includes 1,800 gallons of drip gasoline valued at $357 prepared in Indiana.

Table 4—CLASSIFICATION OF NATURAL GAS GASOLINE BY PRINCIPAL METHODS OF MANUFACTURE

GASOLINE PRODUCED BY COMPRESSION AND BY VACUUM IN 1919

State	Number of plants	Gasoline Produced: Quantity Thousands of Gallons	Gasoline Produced: Value Thousands	Gasoline Produced: Average price Cents	Gas Used: Estimated volume Mil. cu. ft.	Gas Used: Average yield Gallons
Oklahoma	280	175,796	$30,097	17.1	55,966	3.14
California *a*	46	29,483	4,738	16.0	35,639	.83
West Virginia *b*	185	15,795	3,401	21.5	8,354	1.89
Pennsylvania	314	11,683	2,375	20.3	4,931	2.40
Texas	19	6,609	1,101	16.6	3,921	1.70
Louisiana	17	6,397	1,007	15.7	2,093	3.00
Illinois	93	6,057	1,114	18.4	3,160	1.92
Wyoming	3	4,978	823	16.5	1,341	3.71
Ohio	46	2,366	504	21.3	846	2.80
Kansas	10	1,382	284	20.6	1,119	1.23
New York	6	457	84	18.3	237	1.93
Kentucky	6	150	30	20.3	56	2.64
Total, 1919	1025	261,157	45,563	17.4	117,669	2.21
Total, 1918	865	219,767	37,644	17.1	99,897	2.20

a Includes three combination compression and absorption plants.

b Includes two combination compression and absorption plants.

Table 5—CLASSIFICATION OF NATURAL GAS GASOLINE BY PRINCIPAL METHODS OF MANUFACTURE—Continued.

GASOLINE PRODUCED BY ABSORPTION IN 1919 [a]

State	Number of plants	Gasoline Produced: Quantity Thousands Gallons	Gasoline Produced: Value Thousands	Gasoline Produced: Average price Cents	Gas Used: Estimated volume Mil. cu. ft.	Gas Used: Average yield Gallons
West Virginia	42	36,354	$8,778	24.1	158,885	0.22
Oklahoma	49	14,198	2,467	17.3	45,084	.26
California	14	10,902	1,006	9.2	15,358	.70
Pennsylvania	29	8,599	2,032	23.6	51,349	.17
Ohio	13	6,434	1,459	22.7	42,762	.15
Kentucky	3	4,986	1,114	22.3	20,160	.25
Louisiana	6	3,666	659	17.9	24,858	.113
Texas	5	2,727	670	24.6	4,810	.56
Kansas	3	1,901	336	17.7	9,312	.20
Wyoming	2	602	108	17.9	2,346	.257
Total, 1919 [b]	166	90,377	18,633	20.5	[c] 374,928	.24
Total, 1918	139	62,768	12,718	20.3	349,211	.18

a Includes drip gasoline.

b Includes 4,360 gallons of drip gasoline, valued at $755, produced in Illinois and Indiana.

c Includes 12,194,335 Mil. cubic feet of gas that was first treated at compression plants and that is included in the total volume of gas treated at the compression plants but not duplicated in the total for the United States.

Economic Aspects—Although the year 1919 showed a rather marked increase in the growth of the natural-gas gasoline industry its greatest expansion was reached in 1917, when the production was 110 per cent more than that of 1916. This expansion was due to the enormous growth in the demand for gasoline, which led to increased activity in the construction and operation of plants, to greater improvement in plant efficiency, and to the rapid development of the absorption process. At first gasoline was extracted from "wet" natural gas, or that occurring with oil, by the compression process; afterward it was removed from the "dry" gas by the absorption process. "Dry" gas cannot be treated by compression but it contains sufficient gasoline vapors to warrant their extraction by the absorption method.

The outstanding economic features in the natural-gas gasoline industry may be summarized as follows:

1. The industry is constantly expanding and increasing the supply of gasoline.

2. The expansion is due to a greater demand for gasoline and to an increase in the conservation of the total product of most gas fields. The present tendency is to remove the gasoline from gas that is to be used for domestic and industrial purposes, including the manufacture of carbon black.

3. The recovery of gasoline from natural gas does not destroy the gas from which it is taken nor impair its value, but actually benefits it for domestic and industrial use by removing the water, as well as the gasoline, which causes leakage in the conveying pipes by disintegrating the rubber gaskets. The natural-gas gasoline industry is therefore one in which there is 100 per cent conservation.

4. Natural-gas gasoline is highly volatile and must therefore be blended with naphthas, so that the industry has provided a larger market for the blending materials and has brought the oil and gas producer and the refiner into closer relations.

PART TWO

Properties of Gases

PHYSICAL PROPERTIES OF VARIOUS GASES—HYDROCARBONS AND GASOLINE VAPOR

PHYSICAL PROPERTIES OF VARIOUS GASES

In covering this subject fully, a few general definitions and explanations are deemed essential.

As hydrocarbons are the main constituents of casinghead gas, natural gas, gasoline vapor, and oil they are described in detail.

Perfect Gas—A gas which strictly follows Boyle's law is called a perfect gas.

Vapor—Vapor is essentially the same as gas, but the word vapor is conveniently limited to the gaseous state of a body which is liquid or solid at ordinary temperatures, while the term "gas" is applied to aeriform bodies which are in that rarified state at ordinary temperatures.

Vaporize and evaporate have the same meaning—that of changing from a liquid body to a gaseous state.

Distinction Between a Vapor and a Gas—A vapor is a substance in the gaseous state at any temperature below the critical point. A vapor can be reduced to a liquid by pressure alone, and may exist as a saturated vapor in the presence of its own liquid. A gas is the form which any liquid assumes above its critical temperature, and it cannot be liquefied by pressure alone, but only by combined pressure and cooling. The critical point is the line of demarcation between a vapor and a gas. The temperature of the substance at the critical point is the critical temperature. The pressure which at the critical temperature just suffices to condense the gas to the liquid form is called the critical pressure.

Vapor Tension—All liquids tend to assume the gaseous state, and the measure of this tendency is the vapor tension of the liquid.

Table 6—CRITICAL TEMPERATURES AND PRESSURES OF VARIOUS GASES

(Kent)

		Critical Temp. Deg. fahr.	Critical Pressure in Atmospheres	Temp. of Saturated Vapor at Atmos. Press. Deg. fahr.	Freezing Point Deg. fahr.	Density of Liquid at Temperature Given Deg. fahr.
Water	H_2O	689	200	212	32	1 at 39 deg.
Ammonia	NH_4	266	115	—27	—107	0.6364 at 32 deg.
Acetylene	C_2H_2	98.6	.....	—121	—113.8	....
Carbon Dioxide	CO_2	88	75	—112	—69	0.83 at 32 deg.
Ethylene	C_2H_4	50	51.7	—150	—272	....
Methane	CH_4	—115.2	54.9	—263.4	—302.4	0.415 at —263 deg.
Oxygen	O_2	—182	50.8	—294.5	....	1.124 at —294 deg.
Argon	A	—185.8	50.6	—304.6	—309.3	1.5 at —305 deg.
Carbon Monoxide	CO	—219.1	35.5	—310	—340.6	....
Air	......	—220	39	—312.6	....	0.933 at —313 deg.
Nitrogen	N_2	—231	35	—318	—353.2	0.885 at —318 deg.
Hydrogen	H_2	—389	20	—405	....	....

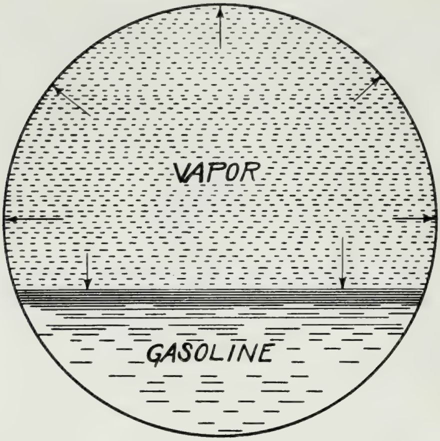


Fig. 11—DIAGRAM OF VAPOR TENSION AND PRESSURE

Vapor Pressure—For a given liquid there corresponds for each temperature a certain definite pressure of its vapor, at which the two will remain in contact unchanged. Thus, in Fig. 11 the gas pressure of the vapor balances the vapor tension of the gasoline. This gas pressure is said to be the vapor pressure of the gasoline at that temperature, and the vapor itself is said to be saturated.

Saturation—A gas is saturated when its full capacity of a given volume of vapor has been reached.

British Thermal Units (B. t. u.)—The B. t. u. standard of determining the quality of natural gas is universally recognized by the natural gas fraternity.

British Heat Unit, or British Thermal Unit, indicates the heat necessary to raise the temperature of one pound of pure water at 39 deg. fahr. through one degree.

There are two methods employed to ascertain the B. t. u. of any gas. One is to use the calorimeter, and the other is to compute it from the gas analysis. In the latter case, it is necessary to have the B. t. u. content of the different gases found in the analysis. These are given on page 117.

GASES

Air—Air is a mechanical mixture of oxygen and nitrogen with about 1 per cent by volume of argon. At 29.318, barometer and 60 deg. fahr., one cubic foot of pure dry air will weigh .07606 lb. and 1000 cubic feet will weigh 76.06 lb.

While the composition of air varies, the following is taken from *Bulletin U. S. Geological Survey, No. 330:*

By Volume				*By Weight*		
N.	O.	Ar		N.	O.	Ar
78.122	20.941	0.937	—	75.539	23.024	1.437

Air expands 1/491.2 of its volume at 32 deg. fahr., for every increase of 1 deg. fahr., and its volume varies inversely as the pressure.

Oxygen O_2—This gas is tasteless, odorless, invisible and slightly heavier than air. It exists in a free state in the atmosphere and in combination in the ocean. It forms about one-fifth of the former and eight-ninths of the latter.

Nitrogen N_2—This is a colorless, odorless, non-combustible gas and is always present in large quantity in gases produced by incomplete combustion. It forms four-fifths of the volume of the air.

Hydrogen H_2—Hydrogen Gas is colorless, odorless, non-poisonous, and the lightest substance known. Hydrogen in a commercial gas makes it lighter, increases the heating value, the amount of air required for combustion, and the heat loss in the products of combustion. It is very combustible, and uniting with oxygen, burns with a pale blue, nearly non-luminous flame, producing water in the form of water vapor. Hydrogen is always a desirable constituent on account of its high calorific power and its avidity for combustion. It will not stand much compression without danger of self-ignition. Its high heating value is 324 B. t. u. per cubic foot at 60 deg. fahr. and 29.33 inches of mercury.*

* This basis of measurement, 60 deg. fahr. and 29.33 inches of mercury (14 65 lb. absolute) is adhered to throughout unless otherwise stated.

Carbonic Oxide—This is also known as carbon monoxide, CO, and is one of the most important constituents of producer gas. It is odorless, colorless, practically insoluble in water, very poisonous, and burns with a distinctive pale blue flame. Its high or gross heating value is 322 B. t. u. per cu. ft.

Carbon Dioxide—It is called carbonic acid and carbonic anhydride, CO_2. It is colorless, odorless, soluble in water, non-combustible, and is formed by the combustion of carbon and oxygen at high temperature.

Natural Gas—Natural gas is a combustible gas that comes from the earth. No doubt it received its name for two reasons, viz.: one on account of it coming naturally from the earth and the other, to distinguish it from artificial or manufactured gas.

Both natural and artificial gas are used for practically the same purposes, viz.: heating, lighting and power.

It would not have been misnamed to have called it methane or marsh gas, as it consists mainly of this hydrocarbon.

In the broad sense of the word one might call carbonic acid, nitrogen, casinghead gas or sulphuretted hydrogen, natural gas, as they all come from wells in the same manner, i. e., in a natural state.

Methane, the main constituent of natural gas, is the lightest known hydrocarbon, having a specific gravity of .559 and at normal temperatures would never exist as a liquid. The boiling point of methane is —256.5 deg. fahr. The natural gas man knows it as a gas only.

Often natural gas carries heavier hydrocarbons, some of which could be properly termed gasoline vapor as they could exist as a liquid at normal temperatures. They exist as part of the gas however, and are just as much an integral part of the whole gas mixtures as the methane itself. One can separate the methane by essentially the same steps as gasoline can be separated, namely, compressors and refrigerators.

Casinghead Gas—Casinghead gas is the name given to the gas which flows from oil wells, and as a rule, comes from the same "sand," or formation, as the oil, and should not be confused with dry or natural gas which comes from a sand other than the oil sand and is usually under high pressure. Its name is derived from the fact that it is taken from the well through the casinghead. It consists of a mixture of the lighter members of the methane series, namely, methane, ethane, propane, butane, pentane, etc., but heavier hydrocarbons than predominant in natural gas.

The gas from different wells varies greatly both in volume and quality. The volume of gas from individual wells ranges from 500 to 1,000,000 cubic feet per day. Extreme variations in volume occur between neighboring wells in the same sand as well as between wells in different sands.

The amount of casinghead gasoline which can be obtained from the gas varies from nothing to as much as ten or twelve gallons per thousand cubic feet. Large variations in "richness" are often found in the gas from wells located quite near each other and in the same sand.

The gas generally comes in through the oil sand with the oil. The pumping of the oil has a tendency to increase the flow of gas from the oil sand. Likewise pumping the gas at a vacuum increases the flow of oil and increases the quantity of gasoline that the gas will pick up. Consequently pumping the gas under a vacuum which increases both the flow of gas and oil is a valuable aid to the oil producer in the production of oil from the well.

Both natural and casinghead gas are mainly composed of hydrocarbons.

The hydrocarbon group is divided into three classes—gaseous, liquid and solid—all of which are in the form of a gas or could be made into gases by application of temperature.

Gaseous hydrocarbons are gases at normal temperatures, can only be liquefied at low temperatures, and will remain in liquid form only when under high pressure.

Liquid hydrocarbons are liquids at normal temperatures and will form a vapor when exposed to air or any other gas. When it is in a vaporized form as in "lean natural gas" it can be absorbed by oil and distilled into a liquid form in which it will remain at atmospheric pressure unless exposed to air or other gas when it will again vaporize slowly.

Solid hydrocarbons will remain as solids at normal temperatures but when heated will liquefy, boil and form vapors. There is no appreciable evaporation from solid hydrocarbons at normal temperatures.

Table 7.

SPECIFIC GRAVITY AND WEIGHT OF GASES AT ATMOSPHERIC PRESSURE AND 32 DEG. FAHR.

(Kent)

	Density Air=1	Density H=1	Grammes per Litre	Lb. per Cu. Ft.	Cu. Ft. per Lb.
Air	1.0000	14.444	1.2931	0.080728	12.388
Oxygen, O	1.1052	15.963	1.4291	0.08921	11.209
Hydrogen, H	0.0692	1.000	0.0895	0.00559	178.931
Nitrogen, N	0.9701	14.012	1.2544	0.07831	12.770
Carbon Monoxide, CO	0.9671	13.968	1.2505	0.07807	12.810
Carbon Dioxide, CO_2	1.5197	21.950	1.9650	0.12267	8.152
Methane, marsh-gas, CH_4	0.5530	7.987	0.7150	0.04464	22.429
Ethylene, C_2H_4	0.9674	13.973	1.2510	0.07809	12.805
Acetylene, C_2H_3	0.8982	12.973	1.1614	0.07251	13.792
Ammonia, NH_3	0.5889	8.506	0.7615	0.04754	21.036
Water Vapor, H_2O	0.6218	8.981	0.8041	0.05020	19.922

HYDROCARBONS

A class of chemical compounds containing only carbon and hydrogen. Their commercial value is very considerable, inasmuch as they form the principal ingredients of petroleum, illuminating gas, caoutchouc, gutta percha, essence of turpentine, coal tar products, etc. They are the simplest of the compounds of carbon, and the fundamental ideas of organic chemistry have been derived largely from a careful study of their properties and reactions. They are obtained when various organic substances are subjected to a process of destructive distillation and are subdivided principally into aliphatic or fatty, aromatic, and hydromatic hydrocarbons.

There are several hundred hydrocarbons known. The term is applied to all compounds consisting only of hydrogen and carbon. *These compounds exist in gaseous, vaporous, liquid and solid states.* Low temperatures are conducive to the formation of the easily condensed, tarry compounds, while with high temperatures, the yield of hydrogen and permanent gases is greatly increased.*

FATTY HYDROCARBONS

The Fatty Hydrocarbons form an important class and are sub-divided into the paraffin, olefin, and acetylene series.

Paraffins—The paraffins, or saturated hydrocarbons of the methane series, are very stable compounds and do not react even with the strongest acids and alkalies; hence their name "paraffins," derived from the Latin parum affinis, which means "having little affinity." Large quantities of them occur in nature as petroleum, natural gas, ozokerite, etc. They are also obtained by the destructive distillation of coal, cannel, shale, etc. When they are arranged in the order of their molecular weights, the following "homologous series" is obtained:

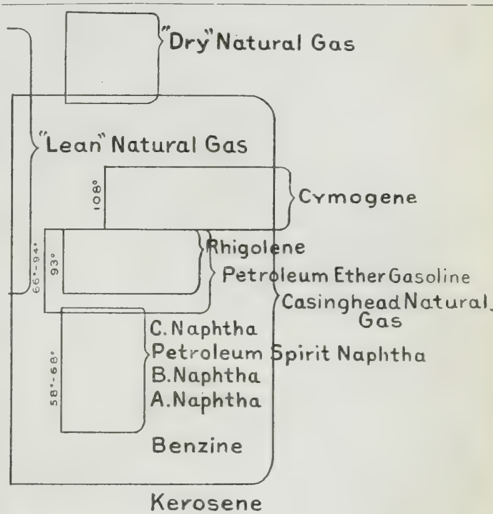
* The New National Encyclopedia.

Methane CH_4	molecular weight	16.
Ethane C_2H_6	molecular weight	30.
Propane C_3H_8	molecular weight	44.
Butanes C_4H_{10}	molecular weight	58.
Pentanes C_5H_{12}	molecular weight	72.
Hexanes C_6H_{14}	molecular weight	86.
Heptanes C_7H_{16}	molecular weight	100., etc.

The difference in molecular weight between any two consecutive members of the series is evidently the same. It amounts to 14, the sum of the "weights" of one carbon atom (which is 12) and two hydrogen atoms (which is 2). To obtain the formula of any member, we may substitute a methyl group CH_3, in place of a hydrogen atom in the member immediately preceding it. Thus, by substituting CH_3 in place of one H in ethane, C_2H_6 we get propane $C_2H_5CH_3$ or C_3H_8. The transformation of ethane into propane may be actually effected as follows: First mono-iodio-ethane (C_2H_5I) is obtained by substituting one iodine atom in lieu of one atom of hydrogen in ethane (C_2H_6); then mono-iodio-ethane is treated with methyl iodide (CH_3I) and metallic sodium. The iodide is thus all removed and the remaining C_2H_5 group unites with the CH_3 group to form the compound propane, ($C_2H_5CH_3$ or C_3H_8).

The first four members of the above homologous series are liquefiable gases, and each member is more easily liquefied than the one preceding it; the next 11 members are ordinarily liquids, each having a higher boiling point than the one preceding it; finally the higher members are ordinarily solids, each having a higher melting point than the one preceding it. The lower members burn with a pale, scarcely luminous flame; the higher members give a bright light, and paraffin wax, which is a mixture of solid paraffin hydrocarbons, is used for the manufacture of candles. The paraffins are all colorless, chemically inert, and insoluble in water.

imum cent- Ex- sive xture	C=Colorless L=Luminous O=Odorless T=Tasteless	Name	COMMERCIAL NAME AND BAUME DEGREE RANGE
4.5	C L O T	Methane	
	C L	Ethane	
	C L	Propane	
	L	Butane	
	All these compounds are colorless liquids. (White Solids.)	Pentane	
.17		Hexane	
1.86		Heptane	
1.64		Octane	
.00		Nonane	
		Decane	
		Undecane	
		Duodecane	
		Tridecane	
		Tetradecane	
		Pentadecane	
		Hexadecane	
		Heptadecane	
		Octadecane	
		Nonadecane	
		Eicocane	



		Other Gases
		Air
	C O T	Carbon Dioxide
		Hydrogen
	C O T	Nitrogen
		Oxygen

Note	Critical Temp.	Critical Pressure
Water	364 deg. cent.	2925 lb.
Carbon Dioxide	31 deg. cent.	1155 lb.
Hydrogen	—241 deg. cent.	225 lb.
Nitrogen	—145 deg. cent.	510 lb.
Oxygen	—118 deg. cent.	750 lb.
Methane	85 deg. cent.	825 lb.
Ethane	35 deg. cent.	678 lb.

The composition of any single paraffin hydrocarbon is expressed, of course, by its own molecular formula. Thus, the formula, C_2H_6 shows the chemical composition of ethane; the formula C_3H_8 shows the composition of propane, etc. On the other hand, the composition of the paraffin hydrocarbons in general is expressed by a typical formula in which algebraic symbols stand for the numbers of atoms of the component elements. This typical (general) formula is C_nH_{2n+2}. The formula permits us to calculate the number of its hydrogen atoms in any one of the members of the above homologous series, if the number of its carbon atoms is given. Thus, if $N=1$ then $2_n+2=4$ and C_nH_{2n+2} becomes CH_4 (the formula of methane). The highest member of the series that is actually known to chemists contains 60 carbon atoms, and hence, the typical formula tells us, the number of hydrogen atoms in the molecule of that hydrocarbon (called hexacontane) is $2_n+2=2\times60+2=122$, and its molecular formula is therefore $C_{60}H_{122}$. It is a well known fact that compounds exist which have the same chemical properties. Such compounds are termed isomeric, and their mutual relations are explained on the assumption that the atoms in their molecules, though the same in kind and number, are differently grouped. In the above homologous series the first three members have no such isomers, i. e., only one variety of each could be obtained; the fourth member, butane, has two isomers (called butane and issobutane); the fifth member, pentane, has three isomers; the sixth, hexane, has five isomers, etc. The higher the molecular weight, the greater the number of isomeric formulas which could be constructed according to the structural theory. Not all of these theoretically possible hydrocarbons have been actually prepared in the laboratory. Most of them have no practical value and are interesting only inasmuch as they go to prove the validity of the "structural theory" of compounds; but the number of cases of isomerism

in which the theory has been found to hold true is so great that chemists are no longer desirous of obtaining new proofs by artificially producing all of the possible isomeric compounds.

Olefins—The olefins, or hydrocarbons of the ethylene series, have the characteristic property of directly taking on bromine and other elements to form additive products. This shows that the combining capacity of the carbon contained in them is not completely satisfied by their hydrogen; so they are said to be "unsaturated compounds."

When arranged in order of their molecular weights they form the following homologous series:

Ethylene	$C_2 H_4$	molecular weight 28.
Propylene	$C_3 H_6$	molecular weight 42.
Butylenes	$C_4 H_8$	molecular weight 56.
Amylenes	$C_5 H_{10}$	molecular weight 70.
Hexylenes	$C_6 H_{12}$	molecular weight 84., etc.

In this series, again, each member contains one carbon and two hydrogen atoms more than the member immediately preceding it; i. e., the difference in molecular weight between any two consecutive members of the series amounts to 14. Here, too as in the paraffin series, a certain regularity is found in the variation of the physical properties of the compounds on passing up the series. The first four members are gases and each one is more easily liquefied than the one preceding it. Hexylene and the following 13 members are liquids each one boiling at a higher temperature than the one preceding it. The higher members are solids and each one has a higher melting temperature than the one preceding it. The olefins are colorless and insoluble in water. They contain a high percentage of carbon and burn with luminous flame.

The composition of all the olefins is expressed by the typical formula of the series $C_n H_{2n}$. The ratio of the numbers of hydrogen and carbon atoms is the same throughout the series, showing that the different members of the series have all the same percentage composition. They are, how-

ever, not isomeric in the ordinary sense of the term; for their molecules evidently contain different numbers of atoms. Thus, ethylene (C_2H_4) contains two carbons and four hydrogens; propylene (C_3H_6) three carbons and six hydrogens, etc. But beginning with butylenes, each single member represents several compounds which must be considered as isomeric since they have precisely the same molecular composition and yet differ in their properties. The structural theory lets us forsee the existence of three isomeric butylenes, five amylenes, 13 hexylenes, etc. Again, as in the paraffin series, the higher the molecular weight, the greater the number of isomers possible, according to both theory and experience.

Hydrogen, particularly in the presence of a catalyzer, like platinum black, adds itself to the olefins (unsaturated) yielding hydrocarbons of the paraffin series (saturated).

Another interesting group of unsaturated hydrocarbons have come into prominence in recent years. The best known examples of these are triphenylmetyhl and tribiphenylmethyl. In these the atoms of carbon are not quadrivalent as usual, but trivalent.

Acetylenes—The acetylene hydrocarbons when arranged in the order of their molecular weights form the following homologous series:

Acetylene	C_2H_2	molecular weight 26.
Allyelene	C_3H_4	molecular weight 40.
Crotonylene	C_4H_6	molecular weight 54., etc.

Like any other homologous series, the acetylene series present a certain amount of regularity in the variation of the physical properties of the compounds with increase of their molecular weights.

The acetylenes are unsaturated; in fact they are doubly unsaturated compounds as is shown by their capacity for taking on bromine and other elements to form additive products. The acetylene hydrocarbons burn with a very smoky flame unless by some method enough oxygen is supplied to

burn up completely the large amount of carbon they contain. The general formula of the series is $C_n H_{2n-2}$. Nascent hydrogen adds itself to the acetylene hydrocarbons, yielding still unsaturated hydrocarbons of the ethylene series.

Methane, Marsh Gas, or Fire-Damp—A combustible gas, having the chemical formula CH_4. The name "methane" is derived from the fact that this gas is closely related to "methyl alcohol," the word "methyl" being itself derived from the two Greek words which signify "wood spirit." The name "marsh gas" is given in allusion to the fact that methane is formed, in nature, by the decomposition of dead leaves and other vegetable matter, in wet, marshy places Miners call the gas "fire-damp," from the fact that it occurs in coal mines, where it sometimes forms explosive mixtures with the air, detonating violently when ignited by contact with the naked flame of a lamp. The expression "fire-damp" does not imply the presence of moisture, "damp" being here used in the sense of "vapor." (Compare the German word "Dampf"). To prevent the disastrous explosions of fire-damp in mines, Sir Humphrey Davy invented a form of lamp of wire gauze, the gauze permitting the access of air to the flame, while preventing the passage of flame from the interior of the lamp to the air of the mine. "This action of wire gauze will be readily understood by bringing a piece of such gauze down upon the flame of a candle, and noting that the candle flame does not pass through it." The Davy safety lamp is now used only in mines in which the evolution of methane is unusually abundant, free ventilation by means of blowers or fans being quite sufficient to prevent explosions in most cases, especially in the mines of the United States. Methane is formed in large quantities during the destructive distillation of wood and it also constitutes more than a third of the bulk of illuminating gas, as prepared by the distillation of coal. Pure methane is most conveniently generated by heating sodium

acetate ($NaC_2H_3O_2$) with caustic soda ($NaOH$), methane and sodium carbonate being formed, as indicated by the equation $NaC_2H_3O_2 + NaOH = Na_2CO_3 + CH_4$. It may also be prepared by passing a mixture of carbon dioxide and the vapor of carbon disulphide over red-hot metallic copper; this reaction being of interest to the chemist, because it illustrates the formation of a hydrocarbon from substances which are admittedly inorganic in nature. Methane is the lightest known gas, with the exception of hydrogen and helium. Its specific gravity, as compared with air at the same temperature and pressure, is about 0.553. It has been liquefied by simultaneous exposure to great cold and to high pressure. When compressed under a pressure of 30 atmospheres, in the presence of water and at a temperature below 32 deg. fahr., it forms a crystalline hydrate which decomposes again into water and methane when the temperature is raised and the pressure removed. Methane is of the greatest importance in theoretical chemistry, since the entire series of fatty compounds may be considered to be derived from it, by replacing its hydrogen atoms by atoms of other kinds, or by organic radicals. Indeed, Kekule regarded all organic compounds as derivatives of methane. Methane burns with a bluish-yellow flame, which is almost non-luminous. It was formerly called "light carburetted hydrogen," in distinction from ethylene, which was known as "heavy carburetted hydrogen," or as "bicarburetted hydrogen." Methane is classed as a paraffin, being the simplest member of the paraffin group.

Methane can also be synthetized directly from its elements by passing hydrogen through a heated tube containing reduced nickel mixed with finely divided carbon obtained by previously decomposing methane. An equilibrium is attained corresponding at 475 deg. cent., and one atmosphere with 51 per cent of methane, $CH_4\ C + 2H_2$.

The gross heating value of methane is 1003 B. t. u. per cubic foot at 60 deg. fahr. and 29.33 inches of mercury (14.65 pounds per square inch absolute).

Ethane—Ethane C_2H_6, the next member of the marsh gas series, is sometimes found in considerable quantities in natural gas. It greatly resembles methane in its general properties, but it is better fuel, and burns with a more luminous flame, making it a better illuminant than methane. The heat value per cubic foot is 1754 B. t. u.

Ethane contains 79.96 per cent of carbon and 20.04 per cent of hydrogen by weight.

Propane—$C_3H_8 = CH_3—CH_2—CH_3$. One of the constituents of petroleum, and produced by the action of zinc and hydrochloric acid on isopropyl iodide. It is a gas, soluble in one-sixth of its volume of alcohol.

Butane—A compound also called Tetrane, C_4H_{10}. It exists in two modifications. (1) Normal Butane, $CH_3CH_2CH_2CH_3$ or Diethyl, a paraffin hydrocarbon occurring in petroleum. It is a colorless gas which may be condensed into a liquid at 1 deg. cent., or 34 deg. fahr. (2) Isobutane $CH_3—CH\left\langle\begin{matrix}CH_3\\CH_3\end{matrix}\right.$ is obtained from tertiary butyl alcohol by converting it into tertiary butyl iodide and acting on that with nascent hydrogen. It is a gas which liquefies at 17 deg. cent.

GASOLINE VAPOR*

"All liquids when exposed to the air or to any gas, gradually change to vapor. The rate at which this change takes place increases as the temperature of the liquid rises. When the vapor is being formed quietly, we speak of the liquid as evaporating or vaporizing. When the temperature is sufficiently high, the vapor forms rapidly in the body of the liquid and appears as bubbles, which rise through the liquid. We say the liquid is boiling, and its temperature is its boiling point. If the liquid is pure, the boiling point will remain constant as long as there is any liquid. If we are dealing with a mixture of two liquids of different boiling

* By O. J. Sieplein, Ph. D.

points the boiling will usually begin at the boiling point of the lower boiling liquid. The temperature will gradually rise as the boiling continues until, as the last portion boils away, the temperature has reached the boiling point of the higher boiling liquid. By boiling the liquid slowly, condensing the vapors and collecting the first portions of condensate separately from the latter ones, we bring about a rough separation of the two constituents of the mixture. This is the principle made use of in the separation of petroleum into its various products by distillation, also in the manufacture of the various distilled liquors.

The boiling point of a liquid varies with the pressure exerted upon the liquid. Thus, water can be made to boil at any temperature from 32 deg. fahr. to 698 deg. fahr. Inasmuch as the normal pressure of the air is fifteen pounds per square inch, and the boiling point of water at this pressure is 212 deg. fahr., we ordinarily speak of 212 deg. fahr. as the boiling point of water.

If we close a vessel partly full of water, with a safety valve set at fifteen pounds, the pressure of the steam, i. e., the pressure on the water, when boiling takes place and the valve is opened, is fifteen pounds greater than the pressure of the air, or a total of thirty pounds. The boiling point of this pressure is 249 deg. fahr. Similarly the boiling point for a gauge pressure of thirty pounds (a total pressure of 45 pounds) is 273 deg. fahr. Speaking of these facts from a mechanical engineer's standpoint, we would say the temperature of saturated steam at fifteen pounds is 249 deg. fahr. and at thirty pounds is 273 deg. fahr.

Previous to 1880, it was thought impossible to liquefy certain gases such as air and hydrogen. These were therefore known as permanent or perfect gases. Following up the work of Cailletet, Pictet, Dewar and others in the perfection of means of producing and maintaining cold, all gases have been liquefied. The last to be liquefied was helium,

an inert gas first discovered in the sun and later found to be present in the air and some minerals. The boiling point of helium is the lowest known, it being 451.6 deg. fahr. below zero. The invention by Dewar of vacuum-jacketed vessels aided more than any one other thing in the development of our knowledge in this field. This invention has become of commercial importance, its outgrowth being the vacuum-jacketed bottle such as the thermos.

It was early recognized that there is a certain definite temperature for each substance above which it cannot be liquefied by pressure. This temperature is known as the critical temperature, and the pressure needed to produce the liquid at this temperature is the critical pressure. An example will make this point clear.

The critical temperature of water is 698 deg. fahr; its critical pressure is 2,933 pounds per square inch. This means that at a temperature below 698 deg. fahr. steam may be converted to liquid water by application of pressure, and that at 698 deg. fahr. a pressure of 2,933 pounds is necessary. Stated otherwise, it means that steam generated at this temperature has an absolute pressure of 2,933 pounds, or a noticeable pressure of 2,918 pounds, the excess above the atmospheric pressure of 15 pounds. At the critical temperature the liquid passes over into the gas without expansion.

The term vapor is now applied to gases below their critical temperatures—that is, to gases which by pressure alone can be converted to liquids. The term, true, perfect or permanent gas, is applied to gases above their critical temperatures.

The volume of a gas is increased by the application of heat. These facts are known to anyone who is observant. Scientific experiment has proven that these changes in volume are perfectly regular for true gases, and are independent of the nature or composition of the gas. The

changes in volume for a given change in temperature or pressure are the same for all true gases. Double pressure reduces the volume of a gas to one-half the original volume; triple pressure reduces it to one-third, etc. Four hundred and sixty cubic feet of gas at 0 deg. fahr. will increase one cubic foot for each degree that the temperature is raised. It would be 470 cubic feet at 10 deg. fahr., 480 cubic feet at 20 deg. fahr., etc. An increase of pressure on a gas meets with a certain resistance, which resistance is expressed as heat, warming the gas. If the change in pressure is gradual, the head is radiated to surrounding objects, and not noticed. If, as in commercial practice, the change in pressure is sudden, the heat does not have opportunity to radiate and the warming of the gas is considerable. Therefore, the volume resulting on doubling the pressure would be more than one-half the original volume, because the temperature of the compressed gas is higher than that of the original gas. This increase of temperature varies with original temperatures, original pressures, final pressures, and also with the amount of radiation. The loss of heat by radiation is dependent on the nature of the containing vessel.

Whenever a gas bubbles through or comes into contact with a liquid, it takes up vapor of that liquid unless it is already saturated with vapor of that liquid. The amount of vapor, as would be inferred from former statements, increases as the temperature rises and is quite independent of the nature of the gas. Inasmuch as in the resulting mixture the gas is mixed with vapor the mixture occupies more space than the original gas. Thus, 1,000 cubic feet of dry air at 50 deg. fahr. will take up nine and one-third ounces by weight of water yielding 1,012 cubic feet of moist air; 1,000 cubic feet of dry air at 80 deg. fahr. will take up twenty-five ounces, by weight, of water, yielding 1,035 cubic feet of moist air.

When natural gas in the earth comes into contact with petroleum it takes up some of the petroleum as vapor.

If the well is under vacuum the boiling points of the various portions are lowered. Thus the temperature of the natural gas is still nearer the boiling points of the gasoline portions and greater evaporation takes place. On the other hand, if the gas is present in the well under high pressure, this pressure on the petroleum raises the boiling points. The temperature of the gas is far from the boiling points of even the gasoline constituents and consequently vaporization is small. This is exactly what we find in practice. From petroleum and gas of the same character, the gas from a well under vacuum is richer in gasoline vapor than that from a well under pressure.

When we have a mixture of gases exerting a certain total pressure, each individual constituent of the mixture exerts that fraction of the total pressure which its volume forms of the total mixture. For example, air is roughly one-fifth oxygen and four-fifths nitrogen. Of the ordinary atmospheric pressure of fifteen pounds, oxygen is exerting one-fifth or three pounds while the nitrogen is exerting four-fifths or twelve pounds. If we fill a cylinder or any other vessel with air, we would find exactly the same ratio of oxygen to nitrogen in all parts of the vessel. That is, the oxygen and nitrogen are each present in all parts of the vessel. Each cubic inch of the vessel would contain 0.07 grains of oxygen and 0.25 grains of nitrogen. This corresponds to one-fifth of a cubic inch of oxygen and four-fifths of a cubic inch of nitrogen, if both gases are under a pressure of fifteen pounds. From five cubic feet of air we could therefore obtain one cubic foot of oxygen and four cubic feet of nitrogen, if all these were under fifteen pounds pressure. From the law of gas volume in relation to pressure, if we transfer the one cubic foot of oxygen at fifteen pounds to a five-cubic-foot cylinder, the pressure in this cylinder would be three pounds. This is one-

fifth of fifteen pounds. Similarly the four cubic feet of nitrogen would exert twelve pounds pressure if transferred to a five-cubic-foot cylinder. Now suppose the five cubic feet of oxygen at three pounds to be added to the five cubic feet of nitrogen at twelve pounds. Suppose also that the space occupied by the mixture be restricted to five cubic feet. The pressure must necessarily be the sum of three pounds and twelve pounds, or fifteen pounds.

In order to condense vapor, pressure must be exerted upon it or it must be cooled. If we wish to condense it by pressure alone, we must exert a pressure slightly greater than the pressure of the vapor when the liquid is boiling at the temperature of the experiment. But if the vapor is present in mixture with another gaseous substance, only a portion of the total pressure is being exerted on the vapor. If the vapor constitutes ten per cent of the mixture, the pressure on the vapor is ten per cent of the pressure on the mixture. In such a case we would need 150 pounds pressure on the mixture to have fifteen pounds on the vapor. With the pressure of fifteen pounds on the vapor, this would condense to a liquid at the temperature at which the liquid would normally boil, when under fifteen pounds pressure.

Commercial cymogene is mainly butane which boils at 34 deg. fahr. That is, at 34 deg. fahr. butane vapor exerts a pressure of fifteen pounds. To condense butane vapor at 34 deg. fahr. to a liquid by the application of pressure, we would need fifteen pounds per square inch. If the butane constituted twenty per cent of a mixture, we would need a total pressure of seventy-five pounds in order to have fifteen pounds on the butane vapor. If the butane were ten per cent of the mixture, a total pressure of 150 pounds would be necessary. With five per cent of butane, a pressure of 300 pounds would be needed. From this it will be seen why one gas may produce gasoline with 75 to 100 pounds, while another gas will need 250 to 300 pounds to produce the same quality of gasoline.

Butane is either liquid or vapor, as temperature and pressure conditions may demand. As a gas it weighs almost exactly twice as much as the same volume of air. As a liquid, it weighs almost exactly (a little over) five pounds per gallon. Air weighs at an atmospheric pressure of 14.7 and zero fahr. temperature 86 pounds per thousand cubic feet. A thousand feet of butane would produce about thirty-four gallons of gasoline. Then when the specific gravity of a gas runs up in the neighborhood of one and a half as referred to air, we may easily suspect that more than three and one-half gallons of condensate can be recovered from it."

Fig. 12. GASOLINE PLANT IN KENTUCKY.

PART THREE

Field Examination.

LEASING DATA, GAS DATA, SAND CONDITIONS, WATER CONDITIONS, RAILROAD FACILITIES AND SUPPLY FIRMS.

The profitable extraction of gasoline from gas depends upon many varying conditions. In the early days of the casinghead gasoline industry, only those fields having a large volume and high quality of gas were considered, enabling companies owning inefficient and expensive plants, to make large profits. As the amount of profit earned by these plants became more generally known, the competition for casinghead gas became keener, resulting in higher prices being paid for the gas, larger investments in plant properties, the development of less promising fields, and smaller recovery of gasoline. There were, of course, many failures and the necessity for a more accurate and detailed investigation of the gas by a prospective operator became apparent.

Proper field examination includes a complete survey of all conditions which affect the prices to be paid for the gas, construction, operation and life of plant. Following is a list of the more important features which have a decided influence on cost of construction and operation. It is essential that all of the data mentioned should be obtained by a gasoline company contemplating entering an oil field, especially where there are no plants in operation to serve as a guide for the course of action.

Leasing Information—1. Full name of oil or gas company incorporated under laws of state of ...., home office, names of President and Secretary. Partnership, names of partners and residence.

2. Local name of lease or leases.
3. Owners of royalty interest, addresses.
4. Royalty paid on oil and gas.
5. Owners of land, addresses.

Gas Data:

1. Specific Gravity.
2. Quantity.
3. Quality.
4. Impurities.

Sand Conditions:

1. Thickness.
2. Structure.
3. Salt Water.

Well Information:

1. Number of wells on lease or leases.
2. Acreage per well.
3. Depth.
4. Age.
5. Equipment.
6. Gravity of oil.
7. Decline of oil production.
8. Pumping periods.
9. Number of wells on power line.
10. Total horse power of boilers and engines on power line.

Construction Data:

1. Water Conditions.
2. Road Conditions.
3. Railroad facilities.
4. Supply firms, location and names.
5. Labor supply.

Leasing Data—It is very essential for the gasoline company to obtain complete and exact information to avoid possible future legal difficulties. Frequently companies fail to give much attention to this phase of the business, only to find out later that the royalty is larger than usual or that the leases have not been properly prepared. Usually in a new oil field, leases are taken in a haphazard manner in order to save time and with the hope of being able to complete details later. The completion never takes effect until after legal proceedings have been instituted by one of the interested parties.

Gas Data—The specific gravity of gas must be known to determine the quantity of gas or flow from a well and it forms a very rough indication of the gasoline content of the gas. A fairly representative number of wells should be tested, as the wells on the same lease may vary widely and the same well vary from time to time depending on well conditions and operation. As a general proposition gas having a specific gravity of less than 0.80 (Air = 1) and lower should not be treated by the compression method. The lighter gas should not be mixed with heavier gas in a compression plant but should be treated independently. If there is not a sufficient volume of the lighter gas to warrant the construction of an absorption plant it should not be utilized for gasoline extraction.

The quantity of gas from the same well varies at different times. The gas from wells on a fuel line is known to have declined rapidly in volume and later when permitted to blow in the air increase almost as rapidly so that one should not expect the individual wells to show the same percentage of decrease in quantity in subsequent tests.

Many people in measuring casinghead gas allow for a larger volume than is actually shown, due to the expected effect of the vacuum which will be put on the wells. This has been found to be incorrect as the "head" is soon pulled

off by the vacuum and the volume of gas decreases to the figures shown by the measurements. This is the reason that many leases have not come up in volume to expectations.

The quality or gasoline content per thousand cubic feet may be determined by any of the methods mentioned in Part 7, under testing for gasoline content. The specific gravity of the gas only gives a rough indication of the amount of condensate which may be expected from a given gas and the method of testing which depends upon the percentage of gas absorbed in oil is likewise unreliable for final decision. However, the methods which are described are accurate and give results which compare most favorably with plant operation. They are practical tests by miniature compression and absorption plants and each and all produce a gasoline condensate which can be weathered to its proper specific gravity and vapor tension. Any method which depends upon an emperical formula can not be relied upon to give true results.

The presence of carbon dioxide or air may give misleading results and the samples of gas should be sent to a laboratory to determine if any of these impurities are present. Hydrogen Sulphide may be present. The presence of this impurity can usually be detected by its odor. Gasoline obtained from gas containing this impurity will be of unsalable quality and must be purified before it can be sold at the market price.

Sand Conditions—A thorough knowledge of the sand conditions will be useful in forming an estimate of the probable decline of gas volume in the field. Thick sands are naturally more indicative of long life than thin sands. Likewise a sand of compact fine texture is likely to have a longer life than that of a coarse or porous texture. Quite frequently oil fields are located in regions where the pay sand is not a true sand; for instance, it may consist of porous limestone. These sands are usually short lived, producing large quantities of

gas and oil for very short periods of time and frequently become exhausted very suddenly. Loose coarse sands are not desirable from a gasoline stand point. When a vacuum is placed on the well, if it is not handled very cautiously, a heavy vacuum will cause the sand to be pulled into the well necessitating frequent cleaning. It is very likely to shut off entirely the flow of oil and gas. A vacuum should not be placed suddenly on any sand. It should be applied gradually and the effect on gas and oil production should be carefully noted. Many oil fields have been ruined by having a sudden vacuum placed on the wells drilled into loose oil and gas sands. The presence of salt water indicates the closely approaching end of gas flow.

Well Conditions—The number of wells on a lease has an important bearing on the quantity of gas to be obtained from the lease. Wells having a small acreage are shorter lived than those having a large acreage tributary to them. Deep wells, all conditions remaining the same, are longer lived than those located in a shallow sand. The age of the well indicates whether it has had sufficient time to blow off its "head," or whether it is on a settled production basis. New wells decline much more rapidly than wells which are older. The equipment of a well, namely, length of casing, location of working barrel, etc., has an important bearing on the volume of gas to be delivered. The well may not be cased to the sand, permitting the gas, which may not contain a sufficient quantity of the heavier hydrocarbons to form gasoline, to enter the well from a higher sand. Furthermore, if the working barrel is located near the top of the sand the presence of oil in the well may seal the sand and decrease the quantity of gas to such an extent that the flow of gas would be very small or intermittent. A well which has been shut down for some time or which has not been cleaned for a long period may show practically no gas, whereas if it is cleaned and pumped regu-

larly the gas volume may be considerable. This condition is likewise due to the oil sealing the sand. Gas coming from wells producing an oil of light gravity usually contains a higher percentage of gasoline fractions than that from low gravity oil wells. The decline in oil production is a rough indication of the possible decline in gas production.

As the pressure in the wells decreases, the gas becomes richer. However, the total amount of gasoline to be recovered gradually decreases though not so rapidly as the volume of gas decreases. Wells which have ceased producing oil for years are still producing casinghead gas in sufficient quantities to maintain successful plants. Pumping periods have their influence on gas production as the supply of gas will be lower when the well is shut down than when it is being pumped. Some oil companies pump their wells during certain hours each day. If the quantity of gas on a lease was determined when all the wells were being pumped, the amount shown would exceed the amount to be obtained when the wells were not being pumped and consequently the total time when wells are allowed to stand should be deducted from the output as indicated when wells are being pumped.

When the wells are widely distributed it is possible that two or three small plants will be more profitable than one large central plant with its greater piping system and numerous booster stations. The number of wells on fuel or power line is useful in determining the percentage of wells under a pressure. This pressure naturally decreases the amount of gas to be obtained from such wells. A rough idea of the amount of gas obtained from the wells on the fuel line can be obtained if the total horse power of boiler and engines utilizing this gas is known. Estimate that 60 cubic feet per hour per horse power will be used under a boiler and 15 cubic feet per horse power per hour in a gas engine.

As was noted, each one of the above items has their effect on the quality or quantity of gas produced from the

lease. Many plants have been constructed larger in capacity than was actually needed to handle all the gas which could be delivered to them, due to the fact that the quantity decreased much more rapidly than was anticipated when the original tests were being made. For instance, in a certain field a plant of capacity of 1,500,000 cubic feet per day was constructed and only a maximum 750,000 feet of gas could be obtained when the plant was placed in operation. In another case a gasoline plant and vacuum station were installed, a 9 inch vacuum placed on the wells deriving the oil from a loose porous sand with the result that in a few weeks it was impossible to obtain either oil or gas on account of the wells being clogged with sand.

Water Conditions—An adequate supply of water is essential to all plants making gasoline by the compression method. The compressor jackets and cooling coils of a plant treating 1,000,000 feet of gas daily at a pressure of 250 pounds will use 200 barrels of water a day, on account of evaporation and water being carried away by wind where the towers and sprays are used. In oil fields where fresh water is not obtainable and the only supply consists of mineral or brackish waters, extensive equipment must be installed to furnish water for plant purposes. Water is likewise required in absorption plants for steam boilers, compressor jackets and cooling coils. Impure water should not be used on account of formation of scale which will interrupt the circulation and become dangerous to both machinery and operators. It will also cut down the efficiency of the plant and increase the cost of repairs.

Road Conditions—Most gasoline plants are built in locations which are not readily accessible to railroads necessitating the hauling of all equipment over dirt roads. The hauling item is usually a very large percentage of the cost of the plant and may very easily become a controlling factor. In one instance it cost a company over $200 a ton to haul

light building material four miles from the railroad to the plant on account of the very rough condition of the roads. This company was also unable to move their compressors which had been received at the railroad unloading point during the winter for over six months waiting for roads to improve.

Railroad Facilities—The location of the lease with respect to a railroad affects location of plant, blending, capacity of units and length of pipe lines. Unless the leases are located very close to a railroad, it is better to locate the plant in the center of the leases rather than on the railroad. It is much cheaper to run a line to convey the gasoline from the plant to the railroad siding than it is to transport the gas from the leases to the rallroad and return the residue gas back to the leases.

Supply Firms—The location and names of supply firms should be obtained as the cost and availability of repair parts will have quite a bearing on the amount of duplication, required in a plant to prevent long shut downs and also enable the operator to determine the amount of spare parts which should be carried.

PART FOUR

Gas Lease

GAS LEASE, CONTRACTS, GAS CLAUSE IN OIL CONTRACT, PIPE LINE RIGHT OF WAY CONTRACT.

Prior to the year 1914 practically all the gas which was treated for gasoline was leased by a gasoline company from the owners of oil leases, under varying conditions. Since that time the larger oil companies have installed their own plants, especially where they have a number of leases in the same vicinity producing a total quantity of gas sufficient for the operation of a plant. However, if the oil companies are small and the amount of gas on each property is not sufficient for a plant, it has been found more advisable to lease the gas to an independent gasoline company rather than to another oil company operating in the same vicinity. This eliminates the possibility of the gasoline producing company operating to their own advantage or failing to place a vacuum on the wells of the adjoining oil companies.

The older leases were usually made on a flat rate basis which varied from two to five cents per thousand cubic feet. Often the contract specified the vacuum to be held on the wells, the basis on which the gas was to be measured, that any treated gas not used for operation of the plant was to be returned to the lease for power, that the gasoline company should lay the gathering lines and maintain them in proper condition and in some cases it was required that a certain percentage of the gas delivered to the plant should be returned to the lessee. The following is an example of a general form of lease.

CASINGHEAD GAS CONTRACT

This Memorandum of Agreement, Made and entered into in duplicate on this..day of ....19........, by and between.............................. as party of the first part, and.. as party of the second part.

WITNESSETH

THAT, WHEREAS, The said party of the first part is the owner of certain oil and gas mining leases, hereinafter described, situated in ...., State of ...., and

WHEREAS, said party of the first part is producing what is known as casinghead gas from oil wells on said leases, and the party of the second part desires to utilize the casinghead gas aforesaid, in the manufacture of casinghead gasoline;

NOW, THEREFORE, for and in consideration of the payment of One Dollar ($1.00), receipt whereof is hereby acknowledged, and in consideration of the performance of the mutual promises, covenants and obligations herein set out, it is agreed by and between the parties hereto as follows, to-wit:

FIRST: The party of the first part shall and will furnish at the gathering lines of the party of the second part, and the party of the second part shall and will receive and pay for, as hereinafter provided, all casinghead gas suitable for recovery of gasoline, including all gasoline drip and condensate accumulating in the lines or at the vacuum pumps of the party of the first part that shall be produced or which may hereafter be produced, from the well or wells on the following described leases:

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SECOND: The party of the second part shall, at its own expense, install and keep in repair meters of standard type sufficient in size to measure the number of cubic feet of gas received by it under this agreement. The said meter shall be read daily in accordance with

the rules, methods and instructions of the Metric Metal Works, or other standard forms for the correct reading of such meters and the amount of gas so metered shall be computed on the basis of one (1) pound to a square inch above atmosphere. It is agreed that if for any reason the meter fails to register or incorrectly registers the amount of gas being delivered to the second party, the amount of gas being delivered shall be based on the average per day for the last preceding thirty (30) days multiplied by the number of days the meter failed to register or registered incorrectly. The second party agrees to maintain to the best of its ability the said meter in proper working condition, and, at the option of either party hereto, the said meter may be inspected and calibrated by a competent and disinterested meter man, the party so desiring the inspection and calibration to pay all expenses thereof if the meter is found to be correct within five (5%) per cent.

THIRD: The first party agrees to maintain the casingheads of all its wells and all pipe lines owned by it tight and in good condition to prevent the inleakage of air, and, when any well or wells are being taken out of service for repairs, the first party agrees to shut off same from communication with the gathering main by suitable stopcocks. The second party shall have the right and privilege of refusing to receive gas which contains more than five (5%) per cent of air as determined by an accurate chemical analysis, and at all times the amount of air present in gas, as shown by analysis, shall be deducted from the meter registration of gas, and the amount shall be based on the average of the content observed at the beginning and end of period during which said amount of air is to be deducted.

FOURTH: The second party, by his representatives, shall have at all times the free right of way over any property of the first party whenever said plant and apparatus shall be constructed or erected and after construction and during the full period of operation for the transportation of material and supplies thereto and for all proper purposes.

FIFTH: The said party of the second part hereby agrees to keep accurate and correct accounts in proper books of all gas so delivered, and to render to the party of the first part a statement on or about the twentieth day of each calendar month showing the total amount of gas so delivered and purchased during the preceding month, and to pay the party of the first part a price in accordance with the tariff of rates embodied in Schedule "A" which is attached hereto and made a part of this contract.

SIXTH: The gasoline content or yield of casinghead gasoline from casinghead gas purchased from the party of the first part upon which the price is based as shown in Schedule "A" shall be determined by the test of said gas made in the usual and accepted manner of testing casinghead gas to determine directly the gasoline content of casinghead gas, by compression or absorption methods, and shall be made with the most modern appliances for testing same; said test to be made each three months and its content or yield shown thereby shall be used in determining the sale price or price to be paid for the gas in accordance with Schedule "A" for each succeeding three months or until a further test is made. The party of the second part

shall notify the party of the first part when said tests are to be made, and the party of the first part, if they so desire, may have a representative present to see the making of said test.

SEVENTH: The party of the second part shall have the right to use sufficient residue gas, without charge therefor, to operate its plant, including dwellings erected for its employees. The residue gas shall be delivered back to the party of the first part on his property or lease at a point nearest to the plant of said party of the second part, and in no case shall such amount of residue gas exceed sixty per cent (60%) of gas furnished by said party of first part to party of second part.

EIGHTH: The said party of second part shall have the right to use water from streams and springs and lands of said party of the first part, and to impound same for all such purposes as may be necessary for operation of plants and appurtenances.

NINTH: The terms of this contract shall be co-extensive with the terms of the leases of the party of the first part or any extension thereof.

TENTH: It is understood and agreed that in the event of fire, flood, strike or other happenings beyond the control of the party of the second part causing damage or delay to the machinery, pipe lines, tanks or other facilities of the party of the second part that he shall not be held liable for any of the terms of this contract during such delays, provided repairs are started within a reasonable time to avoid further delay.

ELEVENTH: The party of the second part agrees to commence taking the casinghead gas from the wells of the party of the first part on or about the.............................day of.....................................19........, and to pay for same in accordance with the terms of this contract and agreement.

TWELFTH: This agreement shall extend to and be binding upon the heirs, successors or assigns of both parties hereto.

THIRTEENTH: It is further expressly understood and agreed that the party of the second part shall not in any way whatsoever be liable for gas royalties, rentals or any other expense incident to the operation of said well or wells, and shall only be liable for the payment of gas delivered by the party of the first part into the line of the party of the second part in accordance with the conditions of this contract.

IN WITNESS WHEREOF, the parties hereto have executed this instrument the day and year first above written.

Witness or Attest:

....

....

First Party.

....

....

Second Party.

SCHEDULE "A."

Gallons of gasoline per M. cu. ft. of gas.	Price per M. cu. ft.
1	2.5c
1½	3.75c
2	5.0c
2½	6.25c
3	9.0c
3½	11.5c
4	14c
4½	16c
5	20c
5½	25c

Another form is a sliding-scale lease which provides that when the lessor receives a certain average price per gallon for gasoline in tank car lots during the month, the lessee shall receive a specified percentage of this price and a certain advance for each advance in an average price received by the lessor for the gasoline. This form of contract is principally used in the Mid-Continent fields. Oklahoma leases have been made out on what is known as the 4-10 or the 5-10 basis. This means that the price paid for the privilege of extracting gasoline from the gas is to be four cents or five cents per thousand cubic feet when the price received for the product is ten cents per gallon, with an increase of one cent per thousand cubic feet of gas for each additional two cents per gallon received for the gasoline. On the 4-10 basis, with gasoline selling at twenty cents per gallon f.o.b. plant, the price paid for gas would be nine cents per thousand cubic feet. The main objections to this form of lease is that no account is taken of the present or future quantities of condensate in the gas and that as the wells grow older the percentage of gas returning to the original owner becomes practically nothing. In quite a number of plants in the Sistersville, West Virginia district the quantity of residue gas is insufficient to furnish power for the engines. In some cases the plants have been compelled to buy dry gas or electric power to drive

compressors. In some fields the royalty leases are made based either on a percentage of a gross value of gasoline produced or on the net profits of the plant. These leases vary from 1/8 to as high as 1/2 royalty in districts where quantity of gas is large.

Fig. 13

Sale Price Per Gal. or Less	Gallons per 1,000 Cubic Feet																							
	½	1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12
Cents	Cents per 1,000 Cubic Feet of Gas																							
6	¾	2	2	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
7	¾	2	3	5	6	7	8	9	11	12	13	14	15	16	18	19	20	21	22	23	25	26	27	28
8	¾	2	3	5	7	8	9	11	12	13	15	16	17	19	20	21	23	24	25	27	28	29	31	32
9	¾	2	3	6	7	9	11	12	14	15	16	18	20	21	23	24	25	27	29	30	32	33	34	36
10	1	3	4	7	8	10	12	13	15	17	18	20	22	23	25	27	28	30	32	33	35	37	38	40
11	1	3	4	7	9	11	13	15	17	18	20	22	24	26	28	29	31	33	35	37	39	40	42	44
12	1	3	5	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	34	46	48
13	1	3	5	9	11	13	15	17	20	22	24	26	28	30	33	35	37	39	41	43	46	48	50	52
14	1½	4	5	9	12	14	16	19	21	24	26	28	30	33	35	37	40	42	44	47	49	51	54	56
15	1½	4	6	10	12	15	18	20	23	26	27	30	33	35	38	40	42	45	48	50	53	55	57	60
16	1½	4	6	11	13	16	19	21	24	27	29	32	35	37	40	43	45	48	51	53	56	59	61	64
17	1½	4	6	11	14	17	20	23	26	29	31	34	37	40	43	45	48	51	54	57	60	62	65	68
18	2	5	7	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72
19	2	5	7	13	16	19	22	25	29	32	35	38	41	44	48	51	54	57	60	63	67	70	73	76
20	2	5	8	13	17	20	23	27	30	33	37	40	43	47	50	53	57	60	63	67	70	73	77	80
21	2	5	8	14	17	21	25	28	32	35	38	42	46	49	53	56	59	63	67	70	74	77	81	84
22	2	6	8	15	18	22	26	29	33	37	40	44	48	51	55	59	62	66	70	73	77	81	84	88
23	2	6	9	15	19	23	27	31	35	38	42	46	50	54	58	61	65	69	73	77	81	84	88	92
24	2	6	9	16	20	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88	92	96
25	2	6	9	17	21	25	29	33	38	42	46	50	54	58	63	67	71	75	79	83	88	92	96	100
26	3	7	10	17	22	26	30	35	39	43	48	52	56	61	65	69	74	78	82	87	91	95	100	104
27	3	7	10	18	22	27	32	36	41	45	49	54	59	63	68	72	76	81	86	90	95	99	104	108
28	3	7	11	19	23	28	33	37	42	47	51	56	61	65	70	75	79	84	89	93	98	103	107	112
29	3	7	11	19	24	29	34	39	44	48	53	58	63	68	73	77	82	87	92	97	102	106	111	116
30	3	8	11	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120

TABLE 9—SCHEDULE OF PRICES TO BE PAID FOR CASINGHEAD GAS TAKEN FROM INDIAN LANDS IN OKLAHOMA (EXCEPTING OSAGE NATION)

From Regulations to Govern the Utilization af Casinghead Gas Produced from Oilwells on Restricted Indian Lands

GAS CONTRACT

This Indenture, Made and entered into this.................................
day of...19.......................................
by and between...
of...party of the first part,
hereinafter called Seller, and...
of...party of the second part,
hereinafter called Buyer.

WITNESSETH: (1) That in consideration of the sum of One Dollar ($1.00) paid by the Buyer to the Seller, receipt of which is hereby acknowledged, and other payments, covenants, stipulations and conditions hereinafter specified the Seller hereby grants to the Buyer the right to use for the purpose of manufacturing casinghead gasoline, including the operation of gas pumps, gas engines, boilers and other equipment necessary in the conduct of the business, and the Buyer agrees to use for this purpose, all the casinghead gas and all other gas, productive of gasoline in paying quantities, produced from the oil wells now located or hereafter drilled or developed on the lands more particularly described in list hereto attached and made a part of this agreement, marked Exhibit "A."

It is mutually agreed that the Seller shall have first call on all said gas, or as much of it as may be necessary for its operations on the above mentioned lands shown in Exhibit "A," and for lighting and heating the dwelling houses and other buildings upon said lands. It is understood and agreed, however, that the Buyer will lay, at its expense, from its gasoline plant or plants to said leases and lands of the Seller, gas lines to a central point mutually agreed upon or to Seller's vacuum pumps, and agrees to furnish return or dry gas to Seller free of charge, for the purpose of its operations and for heating and lighting the buildings on said lands, the Seller agreeing to give free right-of-way to the Buyer for all gas and gasoline lines on the land and leases above mentioned. IN EVENT SAID BUYER SHALL FURNISH AN AMPLE SUPPLY OF GAS TO SELLER FOR SAID PURPOSES, THE SAID SELLER SHALL NOT RETAIN ANY OF ITS CASINGHEAD GAS, BUT SHALL DELIVER ALL OF SAME TO SAID BUYER.

(2) It is stipulated and agreed that this contract shall be binding on the parties hereto for one year and as long thereafter as gas, productive of gasoline in paying quantities, is produced.

(3) The price to be paid for said gas is shown by table attached to this contract, marked Exhibit "B."

(4) The price per gallon of gasoline upon which price of gas, as shown in Exhibit "B," is to be based, shall be the average selling price of raw casinghead gasoline as sold by the Buyer during each calendar month for which settlement is made.

(5) The yield of casinghead gasoline from gas purchased from the Seller upon which the gas price is based, as shown in Exhibit "B," shall be at the option of the Buyer, either

(a) The average yield of casinghead gasoline per thousand cubic feet of gas utilized at the plant of the Buyer during the month for which settlement is made, (Said yield to be determined by dividing the number of gallons of casinghead gasoline saved or sold by the Buyer by the number of thousand cubic feet of gas utilized at the Buyer's plant during each calendar month for which settlement is made; all losses by evaporation from plant to destination shall be deducted in computing plant production. If any stocks of gasoline are carried into the month or months following that for which settlement is made, losses thereon shall be deducted from the production for the month or months in which said losses occur, or in case of evaporation in tank cars to destination, commonly known as outage, the month or months in which said evaporation or outage reports are received. For example: The number of gallons of gasoline saved or sold during the month after deducting all evaporation losses occurring on stocks of gasoline and reported on cars in transit is 200 gallons. The amount of gas consumed at Buyer's plant is 100,000 cubic feet. The yield is therefore 200 divided by 100 or 2. Thus 2 gallons is the yield per thousand.

—or—

(b) An actual physical field test made under the rules and regulations as prescribed by the Superintendent of the Five Civilized Tribes, governing the sale of gas from restricted Indian lands.

(6) The Buyer agrees to pay for the said gas under the terms and conditions of this contract as specified in the schedule marked Exhibit "B," settlement therefor to be made and paid on or before the 25th of each calendar month next following that in which the gas was delivered.

(7) In the event of handling gas from flowing wells, the Seller is to furnish necessary flow tanks to separate the oil and gas.

(8) All meters necessary for the measurement of gas under this contract shall be furnished by the Buyer, and shall be either a Westcott Proportional, or Westcott Orifice, at the option of the Buyer, and gas measurement by same corrected to a basis of 4-ounce pressure. It is agreed that should the meter, for any reason, fail to work and fail to register the amount of gas delivered to the Buyer, then the amount to be paid for by the Buyer during such time as the meters shall fail to register, shall be the average per day for the last preceding calendar month for which an accurate meter reading was had, multiplied by the number of days during which the meter failed to work or register.

In case any question arises as to the accuracy of the meter measurements at any time, the meter or meters shall be tested upon demand of either party, and the party demanding the test shall pay the expense of such test. No corrections for meter measurements are to be made dating back of the last test prior to the date of complaint.

(9) It is agreed and understood that all gasoline that condenses in lines or drips from the wells to the Buyer's plant shall be the property of the Buyer, and added to the production of gasoline in determining the yield per thousand.

(10) It is further agreed and understood that gas tendered by Seller to the Buyer shall not contain more than 15% air. The Buyer reserves the right to reject any gas containing more than 15% air. It is also agreed that Buyer shall have access to Seller's lines and wells to make necessary tests for air content and shall be permitted to place pressure on lines and wells to make such tests.

(11) The Seller will furnish the Buyer with such water for its operations as in the judgment of the Seller it may furnish to the Buyer without interfering in any way with the operations of the Seller—the Buyer, however, to make reasonable effort to secure water supply independent of any supply of the Seller.

(12) All residue or gas not required by the Seller for the operation of its lease from which gas is taken shall be the property of the Buyer.

(13) It is understood and agreed that all machinery, pipe and equipment of whatsoever nature or kind placed on the lease by the Buyer shall be and remain its personal property and be subject to removal at its option.

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(14) It is understood and agreed that in the event of storm, fire, flood, strikes, water shortage or other happenings beyond the control of the Buyer, causing damage or delay to its machinery, pipe lines, tanks or other facilities, the said Buyer shall not be held liable for any of the terms of this contract during such delay, Buyer using all due diligence to avoid further delay. This same provision shall apply to Governmental restrictions of any kind or character, or any rules or regulations promulgated by the United States Government, or any of its agents, that in any manner interfere with the erection and operation of these plants.

With the exceptions herein enumerated, the said Buyer agrees to receive and pay for all the gas delivered to it by the Seller.

To the faithful performance of each and every term and condition of this contract, we bind ourselves, our legal representatives, successors and assigns, firmly by these presents.

IN WITNESS WHEREOF, the parties hereto have hereunto set their signatures and seals the day and year first above written.
Witness or Attest:

....

....

First Party.

....

....

Second Party.

STATE OF............ }
COUNTY OF........... } ss.

Oklahoma Form of Acknowledgment.

Before me, the undersigned, a Notary Public, in and for said County and State on this..................day of.................., 19......, personally appeared..................

....

and..
to me known to be the identical person......who executed the within and foregoing instrument and acknowledged to me that.................. executed the same as..................free and voluntary act and deed for the uses and purposes therein set forth.

Given under my hand and seal the day and year last above written.

My commission expires..................19

..................Notary Public.

STATE OF............ }
COUNTY OF........... } ss.

Acknowledgment for Corporation.

On this..................day of..................A. D. 19...... before me, the undersigned, a Notary Public, in and for the county, and state aforesaid, personally appeared.................. and..................to me known to be the identical person......who subscribed the name of the maker thereof to the foregoing instrument as its.................. and acknowledged to me that he executed the same as his free and voluntary act and deed, and as the free and voluntary act and deed of such corporation, for the uses and purposes herein set forth.

Given under my hand and seal of office the day and year last above written.

My commission expires..................19......

..................Notary Public.

CASINGHEAD GAS CONTRACT

This Memorandum of Agreement, Made and entered into in duplicate on this the ....day of ....19... by and between.. as party of the first part, and.. ....as party of the second part. WITNESSETH:

THAT, WHEREAS, the said party of the first part is the owner of certain oil and gas mining leases hereinafter described, situated in..............................County, State of.............................., and

WHEREAS, said party of the first part is producing what is known as casinghead gas from oil wells on said lease and the party of the second part desires to utilize the casinghead gas aforesaid, in the manufacture of casinghead gasoline.

NOW, THEREFORE, for and in consideration of the payment of One Dollar ($1.00), receipt whereof is hereby acknowledged, and in consideration of the performance of the mutual promises, covenants and obligations herein set out it is agreed by and between the parties hereto as follows, to-wit:

FIRST: The party of the first part does hereby agree to sell and deliver to the party of the second part all of the casinghead gas now being produced, or which may hereafter be produced from the well or wells on the following described leases:

SECOND: The party of the second part agrees to purchase and to utilize the said casinghead gas in the manufacture of gasoline and shall have the exclusive right to attach to any or all of the said wells which are now being operated or which may hereafter be drilled on the above described premises, such equipment as may be necessary or convenient in order to receive and take the gas agreed to be purchased hereunder.

THIRD: Delivery of such gas shall be made at the wells by the party of the first part to the party of the second part who shall, at his own expense, lay all necessary lines to the wells of the party of the first part and make all necessary connections for the proper receiving of said gas under this agreement. The party of the first part hereby grants to the party of the second part the right to place, erect, maintain and operate on the above described leaseholds, all such materials, pipe lines and other equipment necessary for carrying out and performing the terms of this agreement as will not in any way violate the terms of the leases between the said party of the first part and its lessors and under which said first party is operating said leaseholds, with the full and free right of ingress and egress to, from, over and across said premises for the purposes aforesaid and for the purpose of inspecting said materials, lines and equipment and of transporting and removing the same to, from and over said premises; provided, that in no event shall said second party place or maintain on said premises, without the consent of the owner thereof, any property or material that will in any manner operate as a violation of the terms of said lease or that will create an additional burden thereon in excess of the rights granted by the lessors to the lessee.

FOURTH: The second party agrees to return to the first party at a point designated by the latter, such point not to be more distant from said plant than the average distance of the nearest distant boundary line of the property from which the gas is taken enough gas for the operation of said leases not exceeding, however, eighty per cent (80%) of the amount in quantity of the gas received from the said leaseholds by the party of the second part, such redelivery to be at the cost of the party of the second part.

FIFTH: The party of the second part hereby agrees that when it shall become feasible and advisable to install a vacuum upon the wells of said leaseholds, he will install the necessary equipment and that he will maintain such vacuum on the wells of the party of the first part as may be desired by the party of the first part, provided, however, the party of the second part shall not be required to maintain a greater vacuum on said wells than he maintains on other wells on adjoining leases.

The party of the second part further agrees that prior to the installment of said vacuum that he will not do anything to cause a back pressure to be put upon the above described wells.

SIXTH: The party of the second part shall, at his own expense, install and keep in repair proportional meters of standard type sufficient in size to measure the number of cubic feet of gas received by him under this agreement, together with the usual recording vacuum gauges, a separate meter and gauge to be installed for each of the above described leaseholds, said meters and gauges to be installed on the above described property. The said meters shall be read daily in accordance with the rules, methods and instructions of the Metric Metal Works, or other standard forms for the correct reading of such meters and the amount of gas so metered shall be computed on the basis of four (4) ounces to a square inch above atmosphere. The party of the first part shall have at all times, the right to inspect and test such meters, provided, however, the party of the second part shall be notified in time to be present when such test is made, if he so desires.

And it is agreed that if, after such examination and test, it shall be found that the meter or meters are correctly measuring and registering the said gas, then the expense of such examination and test shall be borne by the party of the first part, but if it shall be found, after such examination, that the said meter or meters are in bad repair, or do not correctly measure or register the gas, then the party of the second part shall correct and repair the same at his own expense and pay the expense of such examination.

SEVENTH: In the event said meter or meters shall be found to be incorrectly measuring the gas, all claims or demands on the part of either party against the other, growing out of failure of the meter or meters to correctly measure said gas, shall be adjusted and settled in the manner following, to-wit:

If said meter or meters have been repaired and do correctly measure the said gas, a ten (10) days continuous gauge shall be taken and the daily average amount of gas passing through the said meter or meters for that period shall be the basis for ascertaining the correct and actual amount of gas received through said meters for the pre-

ceding thirty (30) days. This thirty day period for the purposes of settlement shall be taken as the time or period during which said meter or meters have incorrectly measured the gas unless a settlement shall have been made within said thirty days, in which event the number of days intervening between the commencement of the gauge and the said last settlement shall be taken as the time or period during which the said meter or meters have incorrectly measured the gas.

EIGHTH: The said party of the second part hereby agrees to keep correct and accurate accounts in proper books of all gas so delivered, and to render to the party of the first part a statement on or about the twentieth day of each calendar month, showing the total amount of gas so delivered and purchased during the preceding month, and to pay the party of the first part a price in accordance with the tariff of rates embodied in "Schedule..........." which is attached hereto and made a part of this contract. The sale price as shown on the attached "Schedule................" shall be the same as the average Chicago Tank Wagon market price during each calendar month for Red Crown Gasoline as posted daily by the Standard Oil Company of Indiana.

NINTH: The gasoline content or yield of casinghead gasoline from the casinghead gas purchased from the party of the first part upon which the price is based as shown in "Schedule................" shall be determined by the test of said gas made in the usual and accepted manner of testing casinghead gas to determine the gasoline content of casinghead gas and shall be made with the most modern appliances for testing same. Said test to be made each three months and the content or yield shown thereby shall be used in determining the sale price or price to be paid for the gas in accordance with "Schedule ...." for each succeeding three months or until a further test is made.

The party of the second part shall notify the party of the first part when said tests are to be made and the party of the first part, if they so desire, may have a representative present to see the making of said test.

TENTH: It is further agreed that the books to be kept by the said party of the second part shall be open to the inspection of the said party of the first part at any and all seasonable times.

ELEVENTH: The term of this agreement shall be co-extensive with the terms of the leases of the party of the first part or any extention threof.

TWELFTH: It is understood and agreed that in the event of fire, flood, strike and other happenings beyond the control of the party of the second part, causing damage or delay to the machinery, pipe lines, tanks, or other facilities of the party of the second part, that he shall not be held liable for any of the terms of this contract during such delays, provided repairs are started within a reasonable time to avoid further delay.

THIRTEENTH: The party of the second part agrees to commence taking the casinghead gas from the wells of the party of the first part on or about..19........, and to pay for same in accordance with the terms of this contract and agreement.

FOURTEENTH: This agreement shall extend to and be binding upon the heirs, successors or assigns of both parties hereto.

IN WITNESS WHEREOF the parties hereto have executed this instrument the day and year first above written.

ATTEST: ....
President.

.... By..
Secretary. Party of the First Part.

....
Party of the Second Part.

OKLAHOMA FORM OF ACKNOWLEDGMENT

STATE OF OKLAHOMA,....................}
} ss.
COUNTY OF....................................}

Before me, the undersigned, a Notary Public, in and for said County and State, on this....................................day of...................., 19....., personally appeared ....
....
and..
to me known to be the identical person........who executed the within and foregoing instrument and acknowledged to me that.................... executed the same as....................free and voluntary act and deed for the uses and purposes therein set forth .

IN TESTIMONY WHEREOF, I have hereunto set my hand and affixed my notarial seal the day and year last above written.

My commission expires....................................19........

....Notary Public.

KANSAS FORM OF ACKNOWLEDGMENT

STATE OF KANSAS, }
} ss.
COUNTY OF............................}

BE IT REMEMBERED, That on this............................day of.............
..............................., A. D., 19........, before me, a Notary Public in and for said County and State, came..
and..
who..personally known to me to be the same person........who executed the within and foregoing instrument of writing and as such person........duly acknowledged the execution of the same.

IN WITNESS WHEREOF, I have hereunto set my official signature and affixed my notarial seal the day and year first above written.

My commission expires....................................19........

....Notary Public.

ACKNOWLEDGMENT FOR CORPORATION

STATE OF.............................. }
} ss.
COUNTY OF. }

On this......................day of..A. D. 19........, before me, the undersigned, a Notary Public, in and for the county and state aforesaid, personally appeared... and.. to me known to be the identical person........who subscribed the name of the maker thereof to the foregoing instrument as its.......................... ....and acknowledged to me that he executed the same as his free and voluntary act and deed, and as the free and voluntary act and deed of such corporation, for the uses and purposes herein set forth.

Given under my hand and seal of office the day and year last above written.

My commission expires..19........

....Notary Public.

The amount of royalty or price which can be ordinarily paid for gas depends on quite a number of factors; i.e., quantity of gas per well; whether the wells are widely scattered; gasoline content per thousand cubic feet of gas; whether lessor is required to lay pipe to the wells or not; installation of booster stations; amount of vacuum to be held on the wells; location of plant with respect to transportation facilities; cost of installing plant; the chemical constituents of the gas, that is, whether it contains a large percentage of gasoline fractions or is chiefly made up of the lighter or volatile hydrocarbons; amount of gas which is to be returned to the lease; distance from market; availability of naphtha, etc., for blending; and term of contract. Generally speaking, the price to be paid involves all of the refinements in calculations necessary for any manufacturing enterprise.

GAS CLAUSE IN OIL CONTRACTS

Quite frequently it is specified in the oil lease, that is, the lease between the oil company and the royalty owners, that if the wells produce gas and the gas is sold off the premises, a certain stipulated amount shall be paid from each

well from which gas is sold. Although gasoline has been considered by the courts in some instances as a product of petroleum, nevertheless, the clause mentioned may be so construed as to apply to the extraction of gasoline in which event the amount to be paid to the royalty owner for gas from each well is usually so prohibitive as to eliminate the possibility of a profit. In one field where the gasoline content is two gallons per thousand cubic feet and the amount of gas per well is approximately 3500 cubic feet, the gas clause in the oil leases specify that $100 per well shall be paid per year for gas sold off the premises. At this rate the amount paid the royalty owners would be $100 on a total yield of $420 worth of gasoline, with gasoline at twenty cents per gallon. It is very evident that on this basis the extraction would be absolutely unprofitable or rather leave nothing to be paid to the lease owner. To obviate this condition and avoid any possibility of a legal action it is desirable to obtain consent of the royalty owners to eliminate the operation of the gas clause. A form of consent which has been used is as follows:

CONSENT

The undersigned, being the owner of an undivided.................. royalty in the gas and oil produced and to be produced from the premises described in a certain lease recorded in Volume.................. page..............................County Records, and being what is known as the..............................Farm, in consideration of the sum of One Dollar ($1.00) and other valuable considerations, the receipt of which is hereby acknowledged, do hereby agree:

1. That ....Company, lessee, hereinafter designated as "Company", may enter into a contract upon such terms, for such length of time, for such prices, and with such firm, person or corporation as said company may deem advisable, for the sale of certain oil vapor, sometimes known as casinghead gas, if any may be produced in merchantable quantities, or as shall not be required by said Company for the operation of its wells and leases, the proceeds for such sale to be divided, seven-eights to said Company and one-eighth to be distributed among the respective owners of the royalty.

2. Said contract shall provide that the purchaser shall distribute the proceeds accruing to such royalty owners directly as their respective interests may appear, the undersigned's share to be by check mailed by such purchaser to the address herein given, and the undersigned does hereby absolve and release said .... Company from the collecting of the share accruing to such royalty owner or seeing to the distribution thereof.

3. Said Company is hereby given the right of inserting into such contract such terms and conditions as it deems advisable for the protection of its interests in the oil and vapor and in the reservation of all or any part thereof for the operation of its wells and lease, and the further right to provide for the cancellation of such contract whenever in its discretion it determines that the further sale or marketing of such vapor will be disadvantageous to or a hindrance to the production of oil from said company's wells drilled and to be drilled or the operation of said lease.

That the production, saving or disposing of said oil vapor, (casinghead gas) from such oil wells, or the extraction of the gasoline therefrom shall not cause said wells to be considered as gas wells.

This consent shall be irrevocable so long as the Company shall market said vapor and shall terminate whenever said Company in the exercise of its discretion shall deem it advisable to and shall cancel the contract for the marketing or sale of such vapor as herein provided.

....

....

STATE OF................................ }
} ss.
COUNTY OF.............................. }

I,.., a Notary Public in and for the State and County aforesaid, do hereby certify that the foregoing instrument was produced to me in said County and State, and was acknowledged by ....
to be..............................act and deed for the purposes therein set forth.

My commission expires on the..............................day of..........................
19..........

Given under my hand and seal of office this..........................day of ...., 19..........

....
Notary Public.

County of...................................State of...................................

In cases where the gasoline company lay their pipe lines over various properties not covered in their lease, it is necessary to obtain right of way agreements for the pipe lines. This agreement should be made with the owners of the surface rights of the land. Very frequently these parties are not the same ones who own the royalty. A form of pipe line lease is as follows:

PIPE LINE RIGHT OF WAY CONTRACT

For and in consideration of $.......................to us in hand paid, the receipt of which is hereby acknowledged, we..

....

grantors, do hereby grant to..
a corporation, grantee, its successors or assigns, the right of way from time to time to construct, maintain, operate and remove pipe lines for the transportation of gas and water and a telephone line, if the same shall be found necessary, over and through lands, situated in No.............................Precinct,..............................County......................
bounded and described as follows:

North bounded by..
South bounded by..
East bounded by...
West bounded by...

The said grantors obtained title to said land by.....................................

....

with right of ingress and egress to and from the same. The said grantors, their heirs or assigns to fully use and enjoy the said premises except for the purposes herein before granted to the said grantee which hereby agrees to pay any damages which may arise to the crops and fences from laying, maintaining, operating and removing said pipe and telephone lines; said damages if not mutually agreed upon to be ascertained and determined by three disinterested persons, one thereof to be appointed by the said grantors, their heirs or assigns, one by the said grantee, its successors or assigns, and the other by the two so appointed as aforesaid, and the award of such three persons shall be final and conclusive.

And the said grantee, its successors or assigns, is further granted the right from time to time to change the size of its pipes, the damages, if any, to crops and fences in making such change, to be paid by said grantee, the amount of such damage to be ascertained as above provided. Should more than one pipe line be laid under this grant the said grantee, its successors or assigns, is to pay the said grantors, their heirs or assigns, $.......................for each additional pipe line so laid, besides the same damages aforesaid.

Witness our hands this...............day of.................................., 19.......

....

....

....

Signed, sealed and delivered in presence of

....

....

STATE OF.............................}
                                                    } ss.
COUNTY OF..........................}

I, ..., a Notary Public in and for the County and State aforesaid, certify that the foregoing right-of-way deed from...

....

to..was this day produced to me in the above County and State and acknowledged by the grantors thereto to be their act and deed for the purposes therein contained in the manner required by law.

My commission as Notary Public expires on the......................day of.., 19........

Given under my hand and seal this............day of......................19.......

....Notary Public.

Fig. 14

PART FIVE

Specific Gravity

GAS BALANCE AND EFFUSION METHOD

Specific Gravity—Specific gravity is the ratio between the density of a body and the density of some other body chosen as a standard. The specific gravity of solids and liquids is given in terms of water. In this case the specific gravity is the ratio between the mass of any volume of the substance and the mass of an equal volume of water.

In stating the specific gravities of gases, air is generally taken as a standard. It is very necessary to know the specific gravity of any gas when one is measuring gas by an orifice meter, using an orifice well-tester to determine the flow of a small gas well, or the casinghead gas from an oil well or in testing a large capacity meter with the funnel-meter in the field. It is also of advantage in making preliminary tests as to the quality of casinghead gas.

Edwards Gas Balance—This instrument for determining the specific gravity of a gas, either in the field or in the laboratory, combines portability, simplicity, and extreme accuracy. This instrument is based upon the laws of the compressibility and the buoyant effect of gas. These principles have been used in different forms by different experimenters. The apparatus applicable for field work with natural gas is known as the Edwards Gas Balance. It has been found that this method and apparatus is extremely simple and accurate, and checks are obtained on the same gas to one-tenth of one per cent.*

In the accompanying drawings, figure 16 shows the Edwards Gas Balance completely assembled with mercury manometer "L" at the right in the foreground, hand pump "O" at the left for evacuating the balance chamber, and

* See Technical Paper 89, U. S, Bureau of Standards.

connection "R" to the gas sample by means of the stop cock on the back end of the balance chamber. In the figure 15 is shown the balance beam, consisting of an air tight bulb of spun brass, counter-weighted with adjustable balancing weights. The bearing points are also adjustable, allowing the center of gravity of the beam to be raised or lowered, thus providing a control of the sensibility. The needle points rest on glass bearings.

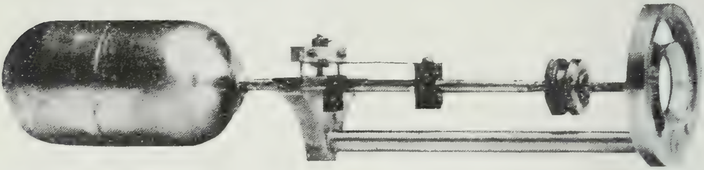


FIG. 15—EDWARDS GAS BALANCE COMPLETELY ASSEMBLED
Pages 291-292 of "Proceedings of Natural Gas Association of America."

The method used for making the test is as follows: The beam is adjusted so that it will come to equilibrium in atmosphere with the counter-weight end slightly below a horizontal plane through the bearing points. In this position a partial vacuum is required to bring it to a level position which is affected by bringing into alignment the cross hair mounted permanently on glass and the line on the end of the balance beam. The air that is allowed into the chamber when making this balance must be drawn through some drying agent assuring dry air. The vacuum reading is then observed on the "U" gauge. This should be repeated and checked. The balancing chamber is then purged of air and the gas allowed to fill it to a pressure sufficient to bring the beam to the same position of equilibrium again. The pressure is then observed on the "U" gauge. These pressures are then reduced to absolute pressure, knowing the barometric pressure at the time of making the test. The specific gravity of the gas is the quotient of the

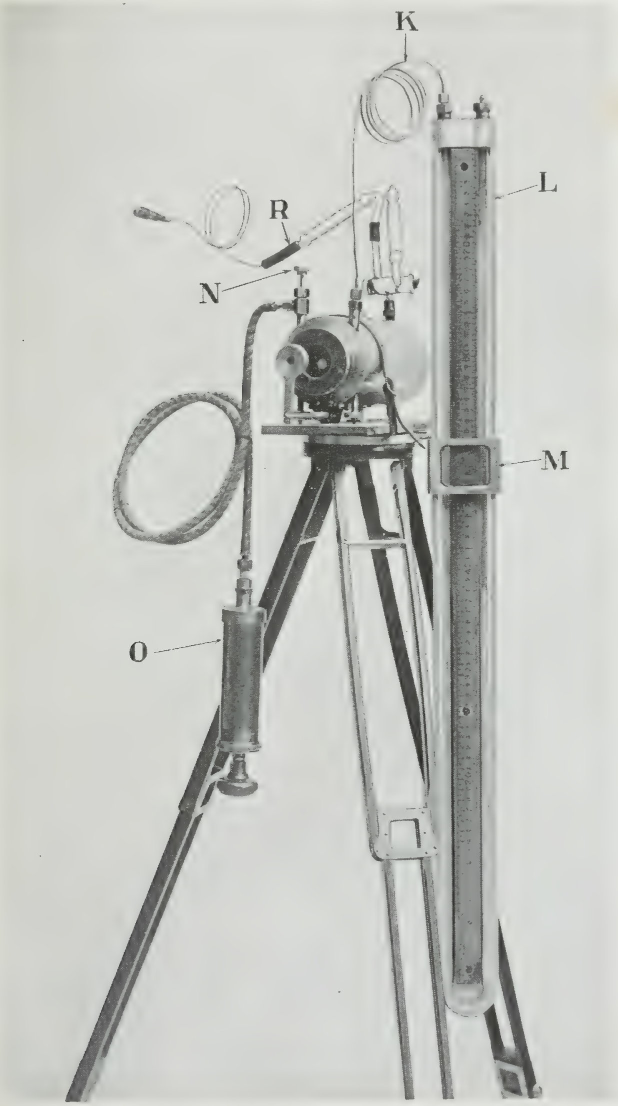


Fig. 16—THE EDWARDS GAS BALANCE

absolute air pressure divided by the absolute gas pressure. (Air being 1). A typical case is given below.

Barometric pressure . . . . 755 mm.
Balancing pressure air . . . . 187 mm. vac.
Balancing pressure gas . . . . 126 mm. pressure

$$\frac{755-187}{755+126}=.6447$$

Bunsen Effusion Method—This method is based upon the fact that the specific gravity of gases is in inverse ratio to the squares of the rates of effusion. For testing casing-head gas, etc., where an accuracy greater than one per cent is not desired, the Bunsen effusion method is satisfactory and very simple. The apparatus is portable and the test can be run very quickly. However, very inaccurate results will be attained unless the orifice tip is calibrated against gases of known specific gravity; if any water is lost from the cylinder between the gas determination and the air determination; or if the tip frosts up in cold weather or if moisture collects on the tip. It seems probable that with the majority of effusion meters an accuracy of about two per cent is secured.

It is essential to know the specific gravity to determine whether the gas volume from any one lease or well is of proper density to carry a sufficient amount of hydrocarbons to warrant having an analysis and test made.

With the outfit shown in Fig. 17 the bottle can be filled with water and carried from one well to another without any danger of losing a drop of it. This permits the taking of several gas tests at various wells after taking but one air test. An air test should be taken at the beginning of each series of gas tests.

By making a gravity test, the density of the gas can be accurately determined. If in testing the gravity of a certain gas it is found to be near .6, which is the gravity

of natural gas, it would be useless to proceed further and have an analysis made, unless one were going to use the absorption process. However, if the gravity proves to be .8 or greater, there would be little doubt of the gas carrying enough hydrocarbons to make it profitable to make gasoline by the compression method.

The method of operation is as follows:

The small glass tube carrying graduations should be placed in the center of the large glass jar while in an upright position.

The large glass jar should be filled with clear water to a little above the top graduation of the small glass tube. This tube should then be withdrawn so as to fill it with air. Prior to placing tube back in the water, shut off the cock on the standard. Remove protecting tube from tip, then open the three-way cock so that the air will pass through the small orifice in the platinum tip.

Before starting the gas tests, the gas should be allowed to flow slowly through the inner tube which is in the jar for several minutes to make sure that it contains no air.

By use of a stop watch, take the time in seconds required for the water level to raise from the 2 inch to the 8 inch graduation as etched on the inner glass tube. Repeat the operation of filling the inner tube with air, passing the air through the small orifice in the platinum tip and timing same at least four or five times.

Then without the loss of any water in the large glass jar or without removing the platinum tip from the ground joint on top of the standard above the cock, connect a common 3/8 rubber hose with the side opening at the three-way cock and allow the gas to pass downward through the inner glass tube while it is in the proper position immerged in the water. This will cause the gas to escape through the water from the bottom of the inner tube into the atmosphere.

Care should be taken that the gas is not turned on too much so that it will cause any water to be lost from the larger jar as the bubbles of gas break through the surface of the water.

This operation assures one of expelling all the air in the inner tube. After continuing this operation for two or three minutes, shut off the gas at the three-way cock and allow the gas in the tube to pass through the small orifice as described in the above paragraph.

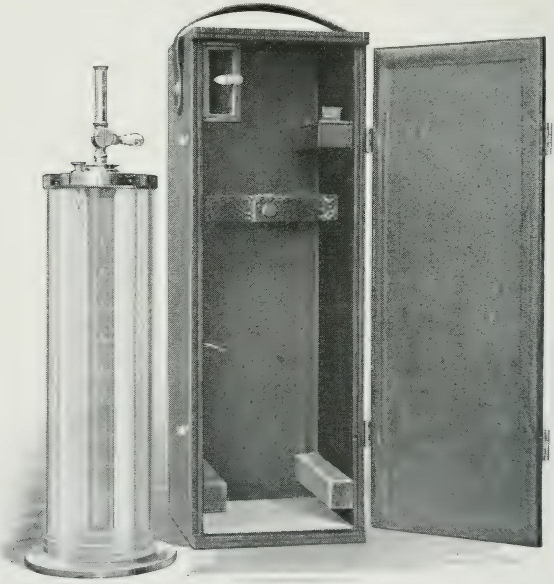


Fig. 17—SPECIFIC GRAVITY APPARATUS AND CARRYING CASE

Repeat the operation at least four or five times, taking the time required for the water level in the inner tube to rise from the 2 inch graduation to the 8 inch graduation, these being the same graduations as used when running the air test.

Average the time required for the air to pass through the small orifice and also, average the time required for the gas to pass through the small orifice, then substitute the figures in seconds for G and A as found in the formula below.

The specific gravity, air being 1, is obtained by dividing the gas time squared by the air time squared.

Formula is—

$$\text{Specific Gravity} = \frac{G^2}{A^2} = \left(\frac{G}{A}\right)^2$$

G = Time gas requires to pass through orifice.
A = Time air requires to pass through orifice.

Boring out the hole in the tip will shorten the time for each individual test, but it will also greatly increase the liability of error in the final results. The longer time it takes for each test, the more accurate the results.

It is good policy not to make any gravity tests during freezing weather, as the orifice in the tip is liable to become frosted, and cause varying and inaccurate results.

This type of specific gravity apparatus is commonly condemned when the operator does not obtain consistent results. In one incident known to the author the results obtained varied from 0.62 to 0.68 specific gravity. Upon immersing the inner glass tube valve and tip under water, it showed several leaks around the joints which would make it impossible to obtain the correct gravity in a test or series of tests. No doubt the leaks had developed through hard usage.

To obtain accurate results the inner glass tube, valve and tip should have no leaks, however small. A considerable error is introduced if any water is lost from the cylinder between the gas determination and the air determination; serious errors are caused if the tip frosts

Fig. 18—The new design inner tube used in Specific Gravity Outfit shown in Fig. 17, page 86

up in cold weather or if moisture collects on the tip. It seems probable that with the majority of effusion meters an accuracy of about two in the second decimal place is secured.

In the following article will be found a full description of the new specific gravity apparatus designed by the Bureau of Standards, together with full instructions for its use.

The new design of inner tube has the same contracted throats at top and bottom as found in the apparatus designed by the Bureau of Standards, and shown in Fig. 19.

For taking specific gravities of gas for meter testing in the field and where the result is not required in thousandths, the apparatus shown in Fig. 17 is well suited.

For coefficients where large volumes of gas are measured and consequently large sums of money are involved, it is best to use the apparatus shown in Fig. 19.

Bureau of Standards Effusion Specific Gravity Apparatus—*"The determination of the specific gravity of gases, that is, their density, or weight, compared with air, is of very great importance for many purposes, both scientific and commercial.

Its accurate determination, as for scientific purposes, is best made by means of the specific gravity balance. This method is fully explained and advised upon in Bureau of Standards Technologic Paper No. 89.

For commercial and ordinary laboratory purposes the effusion method has usually been favored because of the

* From Technologic Paper No. 94, by Junius David Edwards, Assistant Chemist, with alterations and additions.

simplicity of the apparatus required and the readiness and speed with which it can be operated and conveniently taken about.

This effusion apparatus, generally known as the Schilling, after one of its original designers, is embodied, with improvements added, in our portable water-contained type, Catalogue No. 111.

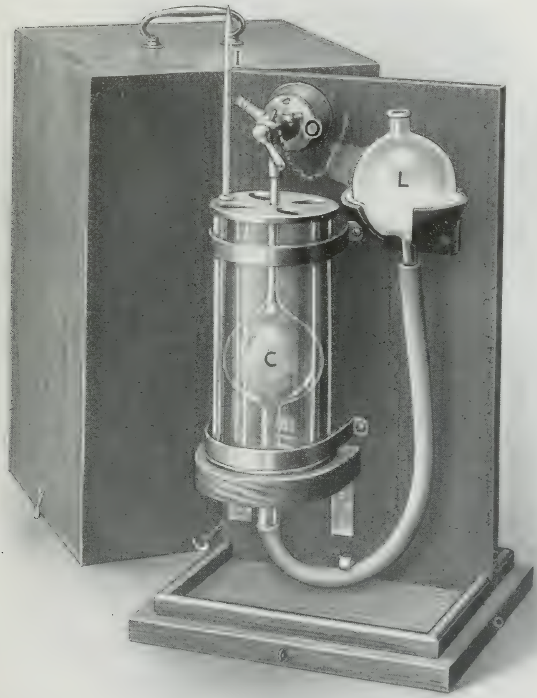


Fig. 19—NEW DESIGN SPECIFIC GRAVITY APPARATUS

The effusion theory on which this apparatus is based is founded upon the fact that the times required for the escape of equal volumes of two gases under the same pressure through the same small orifice are approximately proportional to the square roots of the densities of the gases.

The densities or weights are therefore proportional to the square of the times of effusion.

The specific gravity of a gas is the ratio of the weight of a given volume of the gas to the weight of an equal volume of air, measured at the same temperature and pressure.

Representing the density, or weight, by d and the time of effusion by t, the specific gravity is found as follows:

$$\text{Specific Gravity} = \frac{d\ (\text{gas})}{d\ (\text{air})} = \frac{t^2\ (\text{gas})}{t^2\ (\text{air})}$$

Schilling Apparatus—The Schilling Apparatus is the type which has been most generally used in making such tests. This consists of a glass jar about 3½ in. in diameter and about 12 in. deep, in which is inserted a glass tube about 1 in. in diameter, graduated each inch from the bottom up. This tube is mounted on a brass plate at the top of the jar, through which it is inserted, and attached to it are a 3-way cock and a small glass tip with platinum orifice plate fused across its upper end.

The test is made by filling the jar with water almost to the top, inserting the graduated tube with the cock open so as to allow the water to enter. The tube is now filled with air by withdrawing it with the tip removed and the cock open. It is re-inserted with the cock closed and the tip replaced. The cock key is then turned to permit the air to escape through the orifice tip, being forced out by pressure of the water rising in the tube from the jar.

As the water reaches the first mark the stop-watch is started and is stopped as the water reaches the highest mark. The time of effusion is then noted.

The tube is now filled with gas through a rubber tube attached to the side opening of the cock. The cock is then turned to allow the gas to escape through the orifice while timing in the same manner as with the previous test.

The specific gravity of the gas is then calculated from the square of the times of effusion as previously explained.

Varying results obtained in the use of this apparatus under different conditions and with different gases induced the Bureau to make thorough investigation of the subject in all its phases, as detailed in Technologic Paper No. 94, with the result that a new apparatus was designed, embodying two improvements which reduce inaccuracies to within about 2 per cent., and by the application of correction factors determined by standardization against the specific gravity balance, even closer results are obtained.

The improvements made are, first, in the form of the apparatus and, second, in the orifice tip.

By reference to Fig. 19 it will be noted that the jar and graduated tube are replaced by two bulbs mounted on a stand. The bulb at the right (L) is the water reservoir, or leveling bulb, and takes the place of the jar. The one at the left (C) is used as the gas or air container, having an upper and a lower mark on the tubes extending from it above and below.

The upper tube is of very small bore so as to permit of close observation of the meniscus as the water rises to the mark.

The gas container is set in a jar filled with water to protect it from temperature changes. It is held in position at the lower end by being set through a hole in the bottom of the jar. At the upper end it is attached to a 3-way cock of special design, and is held firmly in place by a metal cap over the top of the jar, through which it extends.

The reservoir at the right rests on a bracket from which it can be lifted and replaced in exactly the same position. The reservoir and the gas container are connected by rubber tubing.

The purpose of using these bulbs is to have less difference in the water levels through extending the body of water laterally. This reduces the effusion pressure of the gas and air to a point at which more accurate results can be obtained than with the tube apparatus.

The orifice tip is redesigned to secure greater accuracy by having the orifice of exact diameter shown by experiments to give closest and most uniform results, viz., about .25 mm. The form of the orifice is perfectly round and the edges sharp and free from burr. This is accomplished by working very carefully under the microscope. To permit of making the orifice of such exact size and shape the plate is of hard material, the platinum being alloyed with 15 per cent. iridium, and the thickness reduced to about .04 mm.

The orifice plate is fused between the ends of two pieces of small glass tubing and the tubing is set with cement into a metal socket, one end of which is threaded inside to screw onto the 3-way cock outlet (O) and the other end is protected by a metal cap when not in use.

The complete apparatus is provided with a centigrade thermometer for the water jar, rubber tubing for the gas inlet (I), an extra orifice tip, and a wooden cover with handle to set over the stand and be attched to it for carrying about.

The apparatus should be set up and filled with distilled water, and with cock open to the air, by pouring into the reservoir in position on the bracket until the water reaches the mark on the upper tube of the gas chamber just below the cock. Preserve this exact amount of water throughout a series of tests, so the effusion pressure will be constant. The water jar should also be filled and the thermometer placed in it to the proper depth through the opening in the plate.

The orifice tip, which is kept screwed on the base of the stand when not in use, is now screwed tightly with a wrench on the outlet of the cock (O), care being taken that the washer is gas tight.

Keep the cock turned so the tip will not connect to the gas container when not in use, thus preventing deposit of moisture in the orifice; also have cock turned off gas container when raising reservoir from the bracket, to prevent water being forced into the cock and thence be carried by the gas or air into the orifice.

The apparatus should be tested to make sure that there are no leaks in the gas chamber.

In filling the apparatus with gas or air, care should be taken to insure an uncontaminated sample by rinsing as many times as may be necessary to obtain constant effusion in successive tests. The orifice tube and connections must also be filled with the gas sample.

When using the movable reservoir, care should be taken to replace the reservoir at exactly the same height, so that the effusion pressure will not be changed from one determination to the next.

Any moisture condensed on the edges of the orifice should be removed by passing dry gas through the orifice. The constancy of the air effusion interval is and indication of whether or not an appreciable error is being introduced from this source.

For a specific gravity determination, several consecutive runs should be made on both gas and air. In general, one should secure three or four intervals which agree within 0.5 per cent., or if the interval be more than two minutes, within one-half second, before the average can be considered as satisfactory. It should be noted that an error of 0.5 per cent. in timing makes a difference of about 1 per cent. in the apparent specific gravity. The accuracy of the stop-watch should be checked by comparison with some standard when possible.

In timing, care should be taken to have the eye on a level with the graduation at the time of starting or stopping the stop-watch.

The water in the jar having been allowed to stand until its temperature is the same as that of the room, and precautions taken to prevent any changes of temperature during the test, the gas container is filled with air through the side cock opening (I) by taking the water reservoir off the bracket and lowering it until the water runs out of the container to a point so far below the mark, on the lower tube, that when the reservoir is raised again and placed on its bracket, with the cock closed to the gas container, the water will not rise above the lower mark.

The air should be held confined in this way until it becomes saturated with water vapor and temperatures equalize. This will also permit drainage of water from the interior surface of the gas chamber. This period of rest should be of uniform duration after each filling before making a test.

The cock is now opened to the orifice tip (O) and the air allowed to escape, the time of effusion being noted with the stop-watch, as the meniscus rises from the mark on the lower tube to the mark on the upper tube, just above the gas container. This operation should be repeated three or four times, so as to obtain an average result.

The gas container should now be filled with the gas to be tested by attaching the rubber tube to the side cock opening (I) and lowering the water reservoir as in filling with air. After the usual period of rest the gas should then be passed out through the orifice and timed as with air, several rinsings being made before the usual series of tests to clear the apparatus of air.

The above experiments having been made with air and gas saturated with vapor water, let S_s represent the specific gravity of the gas tested under these conditions. Therefore, applying the formula already explained, we have:

$$S_s = \frac{t^2 \text{ (gas)}}{t^2 \text{ (air)}}$$

The specific gravity of a saturated gas, however, compared to saturated air, is different from that of the same gas in dry condition compared to dry air.

Moreover, the specific gravity of a saturated gas will vary at different temperatures and pressures.

The different formulas worked out to make correction of these variations for different temperatures, at the standard barometric pressure of 760 mm., have resulted in the following factors represented by "k":

Temperature	k
0°	
0	0.004
5	.005
10	.008
15	.011
20	.015
25	.020
30	.027

If the specific gravity of a gas in dry condition (S) is known, and it is desired to obtain the specific gravity of the saturated gas referred to, saturated air (S_s) at 25 deg. Cent., the following formula is applied:

$$S_s = \frac{S + k}{1 + k}$$

For example: Let S=0.660.

$$\text{Then } S_s = \frac{0.660 + .020}{1.0 + .020} = 0.667$$

If the specific gravity as obtained with an effusion apparatus on saturated gas is to be corrected to that of the dry gas referred to dry air, then the following formula is used:

$$S = S_s \ (1+k) - k$$

Giving S_s at 25 deg. Cent. the value 0.667 as found in the previous example and applying the correction factor k, we have the following result:

$$S = 0.667\ (1 + .020) - .020 = 0.660$$

A further correction may be applied for the particular apparatus in use, if it has been standardized against the specific gravity balance described in Technologic Paper No. 89."

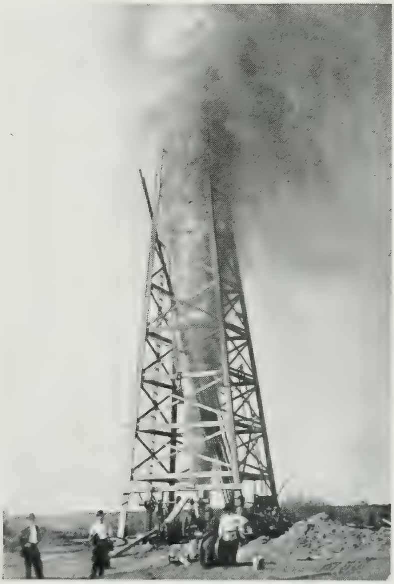


Fig. 20

Table 10—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time 100 to 104 Seconds. Specific Gravity of Air 1.00.

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	100	101	102	103	104		100	101	102	103	104
75.	.562	.551	.541	.530	.520	100.	1.000	.980	.961	.943	.925
75.5	.570	.559	.548	.537	.527	100.5	1.010	.990	.971	.952	.934
76.	.578	.566	.555	.544	.534	101.	1.020	1.000	.980	.962	.943
76.5	.585	.574	.562	.552	.541	101.5	1.030	1.010	.990	.971	.952
77	.593	.581	.570	.559	.548	102.	1.040	1.020	1.000	.981	.962
77.5	.601	.589	.577	.566	.555	102.5	1.050	1.030	1.010	.990	.971
78	.608	.596	.585	.573	.562	103.	1.061	1.040	1.020	1.000	.981
78.5	.616	.604	.592	.581	.570	103.5	1.071	1.050	1.030	1.009	.990
79.	.624	.612	.600	.588	.577	104.	1.081	1.060	1.040	1.019	1.000
79.5	.632	.620	.607	.596	.584	104.5	1.091	1.070	1.050	1.029	1.010
80.	.640	.627	.615	.603	.592	105.	1.102	1.080	1.060	1.039	1.019
80.5	.648	.635	.623	.611	.599	105.5	1.113	1.090	1.070	1.049	1.029
81.	.656	.643	.631	.618	.607	106.	1.124	1.101	1.080	1.059	1.039
81.5	.664	.651	.638	.626	.614	106.5	1.134	1.112	1.090	1.069	1.049
82.	.672	.659	.646	.634	.622	107.	1.145	1.122	1.100	1.079	1.059
82.5	.681	.667	.654	.642	.629	107.5	1.155	1.133	1.111	1.089	1.068
83.	.689	.675	.662	.649	.637	108.	1.166	1.144	1.121	1.099	1.078
83.5	.697	.683	.670	.657	.645	108.5	1.177	1.154	1.131	1.110	1.088
84.	.706	.692	.678	.665	.652	109.	1.188	1.165	1.142	1.120	1.098
84.5	.713	.700	.686	.673	.660	109.5	1.199	1.175	1.152	1.130	1.109
85.	.722	.708	.694	.681	.668	110.	1.210	1.186	1.163	1.141	1.119
85.5	.731	.717	.703	.689	.676	110.5	1.221	1.197	1.173	1.151	1.129
86.	.740	.725	.711	.697	.684	111.	1.232	1.208	1.184	1.161	1.139
86.5	.748	.733	.719	.705	.692	111.5	1.243	1.219	1.195	1.172	1.149
87.	.757	.742	.728	.713	.700	112.	1.254	1.230	1.206	1.182	1.160
87.5	.766	.751	.736	.722	.708	112.5	1.265	1.241	1.216	1.193	1.170
88.	.774	.759	.744	.730	.716	113.	1.277	1.252	1.227	1.204	1.181
88.5	.783	.768	.753	.738	.724	113.5	1.288	1.263	1.238	1.214	1.191
89.	.792	776	.761	.747	.732	114.	1.300	1.274	1.249	1.225	1.202
89.5	.801	.785	.770	.755	.741	114.5	1.311	1.285	1.260	1.236	1.212
90.	.810	.794	.778	.763	.749	115.	1.323	1.296	1.271	1.247	1.223
90.5	.819	.803	.787	.772	.757	116.	1.346	1.319	1.293	1.268	1.244
91.	.828	.812	.796	.781	.766	117.	1.369	1.342	1.316	1.290	1.265
91.5	.837	.821	.805	.789	.774	118.	1.392	1.365	1.338	1.312	1.287
92.	.846	.830	.814	.798	.783	119.	1.416	1.388	1.361	1.335	1.309
92.5	.856	.839	.822	.806	.791	120.	1.440	1.412	1.384	1.357	1.331
93.	.865	.848	.831	.815	.800	121.	1.464	1.435	1.407	1.380	1.354
93.5	.874	.857	.840	.824	.808	122.	1.488	1.459	1.431	1.403	1.376
94.	.884	.866	.849	.833	.817	123.	1.512	1.483	1.454	1.426	1.399
94.5	.893	.875	.858	.842	.826	124.	1.537	1.507	1.478	1.449	1.422
95.	.903	.885	.867	.851	.834	125.	1.562	1.532	1.502	1.473	1.445
95.5	.912	.894	.877	.860	.843	126.	1.588	1.557	1.526	1.496	1.468
96.	.922	.903	.886	.969	.852	127.	1.613	1.581	1.550	1.520	1.491
96.5	.931	.913	.895	.878	.861	128.	1.638	1.606	1.575	1.544	1.515
97.	.941	.922	.904	.887	.870	129.	1.664	1.631	1.599	1.569	1.539
97.5	.951	.932	.914	.896	.879	130.	1.690	1.657	1.624	1.593	1.563
98.	.960	.941	.923	.905	.888	131.	1.716	1.682	1.649	1.618	1.587
98.5	.970	.951	.932	.914	.897	132.	1.742	1.708	1.675	1.642	1.611
99.	.980	.961	.942	.924	.906	133.	1.768	1.734	1.700	1.667	1.635
99.5	.990	.970	.952	.933	.915	134.	1.795	1.760	1.726	1.693	1.660

Table 11—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time 105 to 109 Seconds. Specific Gravity of Air 1.00

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	105	106	107	108	109		105	106	107	108	109
77.5	.545	.535	.525	.515	.506	102.5	.953	.935	.918	.901	.884
78.	.552	.541	.531	.522	.512	103.	.962	.944	.927	.910	.893
78.5	.559	.548	.538	.528	.519	103.5	.972	.953	.936	.918	.902
79.	.566	.555	.545	.535	.525	104.	.981	.963	.945	.927	.910
79.5	.573	.562	.552	.542	.532	104.5	.990	.972	.954	.936	.919
80	.580	.570	.559	.549	.539	105.	1.000	.981	.963	.945	.928
80.5	.588	.577	.566	.556	.545	105.5	1.010	.991	.972	.954	.937
81.	.595	.584	.573	.563	.552	106.	1.019	1.000	.981	.963	.946
81.5	.602	.591	.580	.569	.559	106.5	1.029	1.009	.991	.972	.955
82.	.610	.598	.587	.576	.566	107.	1.038	1.019	1.000	.982	.964
82.5	.617	.606	.594	.584	.573	107.5	1.048	1.028	1.009	.991	.973
83.	.625	.613	.602	.591	.580	108.	1.158	1.038	1.019	1.000	.982
83.5	.632	.621	.609	.598	.587	108.5	1.168	1.048	1.028	1.009	.991
84.	.640	.628	.616	.605	.594	109.	1.178	1.057	1.038	1.019	1.000
84.5	.648	.635	.624	.612	.601	109.5	1.188	1.067	1.047	1.028	1.009
85.	.655	.643	.631	.619	.608	110.	1.098	1.077	1.057	1.037	1.018
85.5	.663	.651	.638	.627	.615	110.5	1.108	1.087	1.066	1.047	1.028
86.	.671	.658	.646	.634	.623	111.	1.118	1.097	1.076	1.056	1.037
86.5	.679	.666	.654	.641	.630	111.5	1.128	1.106	1.086	1.066	1.046
87.	.687	.674	.661	.649	.637	112.	1.138	1.116	1.096	1.075	1.056
87.5	.694	.681	.668	.656	.644	112.5	1.148	1.126	1.105	1.085	1.065
88.	.702	.689	.676	.664	.652	113.	1.158	1.136	1.115	1.095	1.075
88.5	.710	.697	.684	.671	.659	113.5	1.169	1.146	1.125	1.105	1.084
89.	.718	.705	.692	.679	.667	114.	1.179	1.157	1.135	1.114	1.094
89.5	.727	.713	.700	.687	.674	114.5	1.189	1.167	1.145	1.124	1.103
90.	.735	.721	.708	.694	.682	115.	1.200	1.177	1.155	1.134	1.113
90.5	.743	.729	.716	.702	.689	116.	1.221	1.198	1.175	1.154	1.133
91.	.751	.737	.724	.710	.697	117.	1.242	1.218	1.195	1.174	1.152
91.5	.759	.745	.732	.718	.705	118.	1.263	1.239	1.216	1.194	1.172
92.	.768	.753	.740	.726	.712	119.	1.284	1.260	1.237	1.214	1.192
92.5	.776	.761	.748	.734	.720	120.	1.306	1.282	1.258	1.235	1.212
93.	.785	.770	.756	.742	.728	121.	1.328	1.303	1.279	1.255	1.232
93.5	.793	.778	.764	.749	.736	122.	1.350	1.325	1.300	1.276	1.253
94	.802	.786	.772	.758	.744	123.	1.372	1.346	1.321	1.297	1.273
94.5	.810	.795	.780	.766	.752	124.	1.395	1.368	1.343	1.318	1.294
95.	.819	.803	.788	.774	.760	125.	1.417	1.391	1.365	1.340	1.315
95.5	.827	.812	.797	.782	.768	126.	1.440	1.413	1.387	1.361	1.336
96.	.836	.820	.805	.790	.776	127.	1.463	1.436	1.409	1.383	1.358
96.5	.845	.829	.813	.798	.784	128.	1.486	1.458	1.431	1.405	1.379
97.	.853	.837	.822	.807	.792	129.	1.509	1.481	1.453	1.417	1.401
97.5	.862	.846	.830	.815	.800	130.	1.533	1.504	1.476	1.449	1.422
98.	.871	.855	.839	.823	.808	131.	1.557	1.527	1.499	1.471	1.445
98.5	.880	.863	.847	.832	.817	132.	1.581	1.551	1.522	1.494	1.467
99.	.889	.872	.856	.840	.825	133.	1.605	1.574	1.545	1.517	1.489
99.5	.898	.881	.865	.849	.833	134.	1.629	1.598	1.568	1.539	1.511
100.	.907	.890	.873	.857	.842	135.	1.653	1.622	1.592	1.563	1.534
100.5	.916	.899	.882	.866	.850	136.	1.678	1.646	1.616	1.586	1.557
101.	.925	.908	.891	.875	.859	137.	1.702	1.670	1.639	1.609	1.580
101.5	.934	.917	.900	.883	.867	138.	1.727	1.695	1.663	1.633	1.603
102.	.944	.926	.909	.892	.876	139.	1.752	1.720	1.688	1.656	1.626

Table 12—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time 110 to 114 Seconds. Specific Gravity of Air 1.00.

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	110	111	112	113	114		110	111	112	113	114
82.5	.562	.552	.542	.533	.524	107.5	.955	.938	.921	.905	.889
83.	.569	.559	.549	.540	.530	108.	.964	.947	.930	.913	.898
83.5	.576	.566	.556	.546	.536	108.5	.973	.955	.938	.922	.906
84.	.583	.573	.562	.553	.543	109.	.982	.964	.947	.930	.914
84.5	.590	.579	.569	.559	.549	109.5	.991	.973	.956	.939	.923
85.	.597	.587	.576	.566	.556	110.	1.000	.982	.965	.948	.931
85.5	.604	.585	.583	.572	.562	110.5	1.009	.991	.973	.956	.940
86.	.611	.600	.590	.579	.569	111.	1.018	1.000	.982	.965	.948
86.5	.618	.607	.596	.586	.576	111.5	1.027	1.009	.991	.974	.957
87.	.626	.614	.603	.593	.582	112.	1.037	1.018	1.000	.982	.965
87.5	.633	.621	.610	.600	.589	112.5	1.046	1.027	1.009	.991	.974
88.	.640	.629	.617	.606	.596	113.	1.055	1.036	1.018	1.000	.983
88.5	.647	.636	.624	.613	.603	113.5	1.065	1.046	1.027	1.009	.991
89.	.655	.643	.631	.620	.609	114.	1.074	1.055	1.036	1.018	1.000
89.5	.662	.650	.639	.627	.616	114.5	1.083	1.064	1.045	1.027	1.009
90.	.669	.657	.646	.634	.623	115.	1.093	1.073	1.054	1.036	1.018
90.5	.677	.665	.653	.641	.630	116.	1.112	1.092	1.073	1.054	1.035
91.	.684	.672	.660	.649	.637	117.	1.131	1.111	1.091	1.072	1.043
91.5	.692	.679	.667	.656	.644	118.	1.151	1.130	1.110	1.090	1.071
92.	.699	.687	.675	.663	.651	119.	1.170	1.149	1.129	1.109	1.090
92.5	.707	.694	.682	.670	.658	120.	1.190	1.169	1.148	1.128	1.108
93.	.715	.702	.689	.677	.666	121.	1.210	1.188	1.167	1.147	1.127
93.5	.722	.710	.697	.685	.673	122.	1.230	1.208	1.187	1.166	1.145
94.	.730	.717	.704	.692	.680	123.	1.250	1.228	1.206	1.185	1.164
94.5	.738	.725	.712	.699	.687	124.	1.270	1.248	1.226	1.204	1.183
95.	.746	.732	.719	.707	.694	125.	1.291	1.268	1.246	1.224	1.202
95.5	.754	.740	.727	.714	.702	126.	1.312	1.289	1.266	1.243	1.222
96.	.762	.748	.735	.722	.709	127.	1.333	1.309	1.286	1.263	1.241
96.5	.770	.756	.742	.729	.717	128.	1.354	1.330	1.306	1.283	1.261
97.	.778	.764	.750	.737	.724	129.	1.375	1.351	1.327	1.303	1.280
97.5	.786	.772	.758	.744	.731	130.	1.397	1.372	1.347	1.324	1.300
98.	.794	.779	.766	.752	.739	131.	1.418	1.393	1.368	1.344	1.320
98.5	.802	.787	.773	.760	.747	132.	1.440	1.414	1.389	1.365	1.341
99.	.810	.795	.781	.768	.754	133.	1.462	1.436	1.410	1.385	1.361
99.5	.818	.804	.789	.775	.762	134.	1.484	1.457	1.431	1.406	1.382
100.	.826	.812	.797	.783	.769	135.	1.506	1.479	1.453	1.427	1.402
100.5	.835	.820	.805	.791	.777	136.	1.529	1.501	1.175	1.449	1.423
101.	.843	.828	.813	.799	.785	137.	1.551	1.523	1.197	1.470	1.444
101.5	.851	.836	.821	.807	.792	138.	1.574	1.546	1.219	1.491	1.465
102.	.860	.844	.829	.815	.800	139	1.597	1.568	1.241	1.513	1.487
102.5	.868	.853	.838	.823	.808	140.	1.620	1.591	1.563	1.535	1.508
103.	.877	.861	.846	.831	.816	141.	1.643	1.614	1.585	1.557	1.530
103.5	.885	.869	.854	.839	.824	142.	1.666	1.637	1.607	1.579	1.552
104.	.894	.878	.862	.847	.832	143.	1.690	1.660	1.630	1.601	1.574
104.5	.902	.886	.871	.855	.840	144.	1.714	1.683	1.653	1.624	1.596
105.	.911	.895	.879	.863	.848	145.	1.738	1.706	1.676	1.647	1.618
105.5	.920	.903	.887	.872	.856	146.	1.762	1.730	1.699	1.669	1.640
106.	.929	.912	.896	.880	.865	147.	1.786	1.754	1.722	1.692	1.662
106.5	.937	.921	.904	.888	.873	148.	1.810	1.778	1.746	1.715	1.685
107.	.946	.929	.913	.897	.881	149.	1.835	1.802	1.770	1.739	1.708

Table 13—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time **115** to **119** Seconds. Specific Gravity of Air **1.00**.

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	115	116	117	118	119		115	116	117	118	119
85.	.546	.537	.528	.519	.510	110.	.915	.899	.884	.869	.854
85.5	.553	.543	.534	.525	.516	110.5	.923	.907	.892	.877	.862
86.	.559	.550	.540	.531	.522	111.	.932	.916	.900	.885	.870
86.5	.566	.556	.547	.537	.528	111.5	.940	.924	.908	.893	.878
87.	.572	.562	.553	.544	.535	112.	.949	.932	.916	.901	.886
87.5	.579	.569	.559	.550	.541	112.5	.957	.941	.925	.909	.894
88.	.586	.576	.566	.556	.547	113.	.966	.949	.933	.917	.902
88.5	.592	.582	.572	.562	.553	113.5	.974	.957	.941	.925	.910
89.	.599	.589	.579	.569	.559	114.	.983	.966	.949	.933	.918
89.5	.606	.595	.585	.575	.566	114.5	.991	.974	.958	.942	.926
90.	.612	.602	.592	.582	.572	115.	1.000	.983	.966	.950	.934
90.5	.619	.609	.598	.588	.578	116.	1.017	1.000	.983	.966	.950
91.	.626	.615	.605	.595	.585	117.	1.035	1.017	1.000	.983	.967
91.5	.633	.622	.612	.601	.591	118	1.053	1.035	1.017	1.000	.983
92.	.640	.629	.618	.608	.598	119	1.071	1.052	1.034	1.017	1.000
92.5	.647	.636	.625	.614	.604	120	1.089	1.070	1.052	1.034	1.017
93.	.654	.643	.632	.621	.611	121.	1.107	1.088	1.070	1.052	1.034
93.5	.661	.650	.639	.628	.617	122.	1.125	1.106	1.087	1.069	1.051
94.	.668	.657	.645	.635	.624	123.	1.144	1.124	1.105	1.087	1.068
94.5	.675	.664	.652	.641	.631	124.	1.163	1.143	1.123	1.104	1.086
95.	.682	.671	.659	.648	.637	125.	1.181	1.161	1.141	1.122	1.103
95.5	.690	.678	.666	.655	.644	126.	1.200	1.180	1.160	1.140	1.121
96.	.697	.685	.673	.662	.651	127.	1.220	1.199	1.178	1.158	1.139
96.5	.704	.692	.680	.669	.658	128.	1.239	1.218	1.197	1.177	1.157
97.	.711	.699	.687	.676	.664	129.	1.258	1.237	1.216	1.195	1.175
97.5	.719	.706	.694	.683	.671	130.	1.278	1.256	1.235	1.214	1.193
98.	.726	.714	.702	.690	.678	131.	1.297	1.275	1.243	1.232	1.212
98.5	.734	.721	.709	.697	.685	132.	1.317	1.295	1.273	1.251	1.230
99.	.741	.728	.716	.704	.692	133.	1.337	1.315	1.292	1.270	1.249
99.5	.749	.736	.723	.711	.699	134.	1.357	1.334	1.312	1.290	1.268
100.	.756	.743	.731	.718	.706	135.	1.378	1.354	1.331	1.309	1.287
100.5	.764	.751	.738	.725	.713	136.	1.398	1.375	1.351	1.328	1.306
101.	.771	.758	.745	.733	.720	137.	1.418	1.395	1.371	1.348	1.325
101.5	.779	.766	.753	.740	.727	138.	1.440	1.415	1.391	1.368	1.345
102.	.787	.773	.760	.747	.735	139.	1.461	1.436	1.411	1.388	1.364
102.5	.794	.781	.767	.755	.742	140.	1.482	1.457	1.432	1.408	1.384
103.	.802	.788	.775	.762	.749	141.	1.503	1.477	1.452	1.428	1.404
103.5	.810	.796	.783	.769	.756	142.	1.525	1.499	1.473	1.448	1.424
104.	.818	.804	.790	.777	.764	143.	1.546	1.520	1.494	1.469	1.444
104.5	.826	.812	.798	.784	.771	144.	1.568	1.541	1.515	1.489	1.464
105.	.834	.819	.805	.792	.779	145.	1.590	1.562	1.536	1.510	1.485
105.5	.842	.827	.813	.799	.786	146.	1.612	1.584	1.557	1.531	1.505
106.	.850	.835	.821	.807	.793	147.	1.634	1.606	1.578	1.552	1.526
106.5	.858	.843	.829	.815	.801	148.	1.656	1.628	1.600	1.573	1.547
107.	.866	.851	.836	.822	.808	149.	1.679	1.650	1.622	1.594	1.568
107.5	.874	.859	.844	.830	.816	150.	1.701	1.672	1.644	1.616	1.589
108.	.882	.867	.852	.838	.824	151.	1.724	1.694	1.666	1.638	1.610
108.5	.890	.875	.860	.845	.831	152.	1.747	1.717	1.688	1.659	1.632
109.	.898	.883	.868	.853	.839	153.	1.770	1.740	1.710	1.681	1.653
109.5	.907	.891	.876	.861	.847	154.	1.793	1.762	1.732	1.703	1.675

Table 14—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time 120 to 124 Seconds. Specific Gravity of Air 1.00.

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	120	121	122	123	124		120	121	122	123	124
90.	.562	.553	.544	.535	.527	115.	.918	.903	.889	.874	.860
90.5	.569	.559	.550	.541	.533	116.	.934	.919	.904	.889	.875
91.	.575	.566	.556	.547	.539	117.	.951	.935	.920	.905	.890
91.5	.581	.572	.562	.553	.544	118.	.967	.951	.936	.920	.906
92.	.588	.578	.569	.559	.550	119.	.983	.967	.951	.936	.921
92.5	.594	.584	.575	.566	.556	120.	1.000	.984	.967	.952	.937
93.	.601	.591	.581	.572	.562	121.	1.017	1.000	.984	.968	.952
93.5	.607	.597	.587	.578	.569	122.	1.034	1.017	1.000	.984	.968
94.	.614	.604	.594	.584	.575	123.	1.051	1.033	1.016	1.000	.984
94.5	.620	.610	.600	.590	.581	124.	1.068	1.050	1.033	1.016	1.000
95.	.627	.616	.606	.597	.587	125.	1.085	1.067	1.050	1.033	1.016
95.5	.633	.623	.613	.603	.593	126.	1.103	1.084	1.067	1.049	1.033
96.	.640	.629	.619	.609	.599	127.	1.120	1.102	1.084	1.066	1.049
96.5	.647	.636	.626	.616	.606	128.	1.138	1.119	1.101	1.083	1.066
97.	.653	.643	.632	.622	.612	129.	1.156	1.137	1.118	1.100	1.082
97.5	.660	.649	.639	.628	.618	130.	1.174	1.154	1.135	1.117	1.099
98.	.667	.656	.645	.635	.625	131.	1.192	1.172	1.153	1.134	1.116
98.5	.674	.663	.652	.641	.631	132.	1.210	1.190	1.171	1.152	1.133
99.	.681	.669	.658	.648	.637	133.	1.228	1.208	1.188	1.169	1.150
99.5	.687	.676	.665	.654	.644	134.	1.247	1.226	1.206	1.187	1.168
100.	.694	.683	.672	.661	.650	135.	1.266	1.245	1.224	1.205	1.185
100.5	.701	.690	.679	.668	.657	136.	1.285	1.263	1.243	1.223	1.203
101.	.708	.697	.685	.674	.663	137.	1.303	1.282	1.261	1.241	1.221
101.5	.715	.704	.692	.681	.670	138.	1.323	1.301	1.279	1.259	1.239
102.	.723	.711	.699	.688	.677	139.	1.342	1.320	1.298	1.277	1.257
102.5	.730	.718	.706	.694	.683	140.	1.361	1.339	1.317	1.296	1.275
103.	.737	.725	.713	.701	.690	141.	1.381	1.358	1.336	1.314	1.293
103.5	.742	.732	.720	.708	.697	142.	1.400	1.377	1.355	1.333	1.311
104.	.751	.739	.727	.715	.703	143.	1.420	1.397	1.374	1.352	1.330
104.5	.758	.746	.734	.722	.710	144.	1.440	1.416	1.393	1.371	1.349
105.	.766	.753	.741	.729	.717	145.	1.460	1.436	1.413	1.390	1.367
105.5	.773	.760	.748	.736	.724	146.	1.480	1.456	1.432	1.409	1.386
106.	.780	.767	.755	.743	.731	147.	1.501	1.476	1.442	1.428	1.405
106.5	.788	.775	.762	.750	.738	148.	1.521	1.496	1.462	1.448	1.425
107.	.795	.782	.769	.757	.745	149.	1.542	1.516	1.492	1.467	1.444
107.5	.802	.789	.776	.764	.752	150	1.563	1.537	1.512	1.487	1.463
108.	.810	.797	.784	.771	.759	151.	1.583	1.557	1.532	1.507	1.483
108.5	.817	.804	.791	.778	.766	152.	1.604	1.578	1.552	1.527	1.503
109.	.825	.811	.798	.785	.773	153.	1.626	1.599	1.573	1.547	1.522
109.5	.833	.819	.806	.793	.780	154.	1.647	1.620	1.593	1.568	1.542
110.	.840	.826	.813	.800	.787	155.	1.668	1.641	1.614	1.588	1.562
110.5	.848	.834	.820	.807	.794	156.	1.690	1.662	1.635	1.609	1.583
111.	.856	.842	.828	.814	.801	157.	1.712	1.684	1.656	1.629	1.603
111.5	.863	.849	.835	.822	.809	158.	1.734	1.705	1.677	1.650	1.624
112.	.871	.857	.843	.829	.816	159.	1.756	1.727	1.699	1.671	1.644
112.5	.879	.864	.850	.837	.823	160.	1.778	1.749	1.720	1.692	1.665
113.	.887	.872	.858	.844	.830	161.	1.800	1.770	1.742	1.713	1.686
113.5	.895	.880	.865	.851	.838	162.	1.822	1.793	1.763	1.735	1.707
114.	.903	.888	.873	.859	.845	163.	1.845	1.815	1.785	1.756	1.728
114.5	.910	.895	.881	.867	.853	164.	1.868	1.837	1.807	1.778	1.749

Table 15—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time **125** to **129** Seconds. Specific Gravity of Air **1.00**.

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	125	126	127	128	129		125	126	127	128	129
92.5	.548	.539	.530	.523	.514	120.	.922	.907	.893	.879	.865
93.	.554	.545	.536	.528	.520	121.	.937	.922	.908	.894	.880
93.5	.560	.551	.542	.534	.525	122.	.953	.938	.923	.908	.894
94.	.566	.557	.548	.539	.531	123.	.968	.953	.938	.923	.909
94.5	.572	.562	.554	.545	.537	124.	.984	.969	.953	.938	.924
95.	.578	.568	.560	.551	.542	125.	1.000	.984	.969	.954	.939
95.5	.584	.574	.565	.557	.548	126.	1.016	1.000	.984	.969	.954
96.	.590	.580	.571	.562	.554	127.	1.032	1.016	1.000	.984	.969
96.5	.596	.587	.577	.568	.560	128.	1.049	1.032	1.016	1.000	.985
97.	.602	.593	.583	.574	.565	129.	1.065	1.048	1.032	1.016	1.000
97.5	.608	.599	.589	.580	.571	130.	1.082	1.064	1.048	1.031	1.016
98.	.615	.605	.595	.586	.577	131.	1.098	1.081	1.064	1.047	1.031
98.5	.621	.611	.602	.592	.583	132.	1.115	1.098	1.080	1.063	1.047
99.	.627	.617	.608	.598	.589	133.	1.132	1.114	1.097	1.080	1.063
99.5	.634	.624	.614	.604	.595	134.	1.449	1.131	1.113	1.096	1.079
100.	.640	.630	.620	.610	.601	135.	1.166	1.148	1.130	1.112	1.095
100.5	.646	.636	.626	.616	.607	136.	1.184	1.165	1.147	1.129	1.111
101.	.653	.643	.632	.623	.613	137.	1.201	1.182	1.164	1.146	1.128
101.5	.659	.649	.639	.629	.619	138.	1.219	1.199	1.181	1.162	1.144
102.	.666	.655	.645	.635	.625	139.	1.237	1.217	1.198	1.179	1.161
102.5	.672	.662	.651	.641	.631	140.	1.254	1.235	1.215	1.196	1.178
103.	.679	.668	.658	.648	.638	141.	1.272	1.252	1.233	1.213	1.195
103.5	.686	.675	.664	.654	.644	142.	1.290	1.270	1.250	1.231	1.212
104.	.692	.681	.671	.661	.650	143.	1.309	1.288	1.268	1.248	1.229
104.5	.699	.688	.677	.667	.656	144.	1.327	1.306	1.286	1.266	1.246
105.	.706	.694	.684	.673	.663	145.	1.346	1.324	1.304	1.283	1.263
105.5	.712	.701	.690	.679	.669	146.	1.364	1.343	1.322	1.301	1.281
106.	.719	.708	.697	.686	.675	147.	1.383	1.361	1.340	1.319	1.299
106.5	.726	.714	.703	.692	.682	148.	1.402	1.380	1.358	1.337	1.316
107.	.733	.721	.710	.699	.688	149.	1.421	1.398	1.376	1.355	1.334
107.5	.740	.728	.716	.705	.694	150.	1.440	1.417	1.395	1.373	1.352
108.	.746	.735	.723	.712	.701	151.	1.459	1.436	1.414	1.392	1.370
108.5	.753	.741	.730	.719	.707	152.	1.479	1.455	1.432	1.410	1.388
109.	.760	.748	.737	.725	.714	153.	1.498	1.474	1.451	1.429	1.407
109.5	.767	.755	.743	.732	.721	154.	1.518	1.494	1.470	1.448	1.425
110.	.774	.762	.750	.739	.727	155.	1.538	1.513	1.490	1.466	1.444
110.5	.781	.769	.757	.745	.734	156.	1.558	1.533	1.509	1.485	1.462
111.	.789	.776	.764	.752	.740	157.	1.578	1.553	1.528	1.504	1.481
111.5	.796	.783	.771	.759	.747	158.	1.598	1.573	1.548	1.524	1.500
112.	.803	.790	.778	.766	.754	159.	1.618	1.592	1.567	1.543	1.519
112.5	.810	.797	.785	.772	.760	160.	1.638	1.612	1.587	1.562	1.538
113.	.817	.804	.792	.779	.767	161.	1.659	1.633	1.607	1.582	1.558
113.5	.824	.811	.799	.786	.774	162.	1.680	1.574	1.627	1.602	1.577
114.	.832	.819	.806	.793	.781	163.	1.700	1.694	1.647	1.622	1.597
114.5	.839	.826	.813	.800	.788	164.	1.721	1.715	1.668	1.642	1.616
115.	.846	.833	.820	.807	.794	165.	1.742	1.736	1.688	1.662	1.636
116.	.861	.848	.834	.821	.809	166.	1.764	1.757	1.708	1.682	1.656
117.	.876	.862	.849	.836	.823	167.	1.785	1.778	1.729	1.702	1.676
118.	.891	.877	.863	.850	.837	168.	1.806	1.799	1.750	1.723	1.696
119.	.906	.892	.878	.864	.851	169.	1.828	1.820	1.771	1.743	1.716

Table 16—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time 130 to 134 Seconds. Specific Gravity of Air **1.00.**

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	130	131	132	133	134		130	131	132	133	134
97.5	.562	.554	.546	.537	.529	125.	.925	.911	.897	.883	.870
98.	.568	.560	.551	.543	.535	126.	.939	.925	.911	.898	.884
98.5	.574	.565	.557	.548	.540	127.	.954	.940	.926	.912	.898
99.	.580	.571	.562	.554	.546	128.	.969	.955	.940	.926	.912
99.5	.586	.577	.568	.560	.551	129.	.984	.970	.955	.941	.927
100.	.592	.583	.574	.565	.557	130.	1.000	.985	.970	.955	.941
100.5	.598	.589	.580	.571	.562	131.	1.015	1.000	.985	.970	.956
101.	.604	.594	.585	.577	.568	132.	1.031	1.015	1.000	.985	.970
101.5	.610	.600	.591	.582	.574	133.	1.047	1.031	1.015	1.000	.985
102.	.616	.606	.597	.588	.579	134.	1.062	1.046	1.031	1.015	1.000
102.5	.622	.612	.603	.594	.585	135.	1.078	1.062	1.046	1.030	1.015
103.	.628	.618	.609	.600	.591	136.	1.094	1.078	1.062	1.046	1.030
103.5	.634	.624	.615	.606	.597	137.	1.111	1.094	1.077	1.061	1.045
104.	.640	.630	.621	.611	.602	138.	1.127	1.110	1.093	1.077	1.061
104.5	.646	.636	.627	.617	.608	139.	1.143	1.126	1.109	1.092	1.076
105.	.652	.642	.633	.623	.614	140.	1.160	1.142	1.125	1.108	1.092
105.5	.659	.649	.639	.629	.620	141.	1.176	1.159	1.141	1.124	1.107
106.	.665	.655	.645	.635	.626	142.	1.193	1.175	1.157	1.140	1.123
106.5	.671	.661	.651	.641	.632	143.	1.210	1.192	1.174	1.156	1.139
107.	.677	.667	.657	.647	.638	144.	1.227	1.208	1.190	1.172	1.155
107.5	.684	.673	.663	.653	.644	145.	1.244	1.225	1.207	1.189	1.171
108.	.690	.680	.669	.659	.650	146.	1.261	1.242	1.223	1.205	1.187
108.5	.697	.686	.676	.665	.656	147.	1.278	1.259	1.240	1.221	1.203
109.	.703	.692	.682	.672	.662	148.	1.296	1.276	1.257	1.238	1.220
109.5	.709	.699	.688	.678	.668	149.	1.314	1.294	1.274	1.255	1.236
110.	.716	.705	.694	.684	.674	150.	1.331	1.311	1.291	1.272	1.253
110.5	.722	.712	.701	.690	.680	151.	1.349	1.329	1.309	1.289	1.270
111.	.729	.718	.707	.697	.686	152.	1.367	1.346	1.326	1.306	1.287
111.5	.736	.724	.714	.703	.692	153.	1.385	1.364	1.344	1.323	1.304
112.	.742	.731	.720	.709	.699	154.	1.403	1.382	1.361	1.341	1.321
112.5	.749	.737	.726	.715	.705	155.	1.422	1.400	1.379	1.358	1.338
113.	.756	.744	.733	.722	.711	156.	1.440	1.418	1.397	1.376	1.355
113.5	.762	.751	.739	.728	.717	157.	1.459	1.436	1.415	1.393	1.373
114.	.769	.757	.746	.735	.724	158.	1.477	1.455	1.433	1.411	1.390
114.5	.776	.764	.752	.741	.730	159.	1.496	1.473	1.451	1.429	1.408
115.	.783	.771	.759	.748	.737	160.	1.515	1.492	1.469	1.447	1.426
115.5	.790	.777	.766	.754	.743	161.	1.534	1.510	1.488	1.465	1.444
116.	.796	.784	.772	.761	.749	162.	1.553	1.529	1.506	1.484	1.462
116.5	.803	.791	.779	.767	.756	163.	1.572	1.548	1.525	1.502	1.480
117.	.810	.798	.786	.774	.762	164.	1.591	1.567	1.544	1.520	1.498
117.5	.817	.805	.792	.780	.769	165.	1.611	1.586	1.563	1.539	1.516
118.	.824	.811	.799	.787	.775	166.	1.631	1.606	1.582	1.558	1.535
118.5	.831	.818	.806	.794	.782	167.	1.650	1.625	1.601	1.577	1.553
119.	.838	.825	.813	.801	.789	168.	1.670	1.645	1.620	1.596	1.572
119.5	.845	.832	.820	.807	.795	169.	1.690	1.664	1.639	1.615	1.591
120.	.852	.839	.826	.814	.802	170.	1.710	1.684	1.658	1.634	1.609
121.	.867	.853	.840	.828	.815	171.	1.730	1.704	1.678	1.653	1.628
122.	.881	.867	.854	.841	.829	172.	1.751	1.724	1.698	1.672	1.648
123.	.896	.882	.868	.855	.843	173.	1.771	1.744	1.718	1.692	1.667
124.	.910	.896	.882	.869	.856	174.	1.791	1.764	1.738	1.712	1.686

Table 17—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time **135** to **139** Seconds. Specific Gravity of Air **1.00.**

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	135	136	137	138	139		135	136	137	138	139
100.	.549	.540	.533	.525	.518	130.	.927	.914	.900	.887	.875
100.5	.554	.546	.538	.530	.523	131.	.942	.928	.914	.901	.888
101.	.560	.552	.544	.536	.528	132.	.956	.942	.928	.915	.902
101.5	.565	.557	.549	.541	.533	133.	.971	.956	.942	.929	.916
102.	.571	.562	.554	.546	.538	134.	.985	.971	.957	.943	.929
102.5	.576	.568	.560	.552	.544	135.	1.000	.985	.971	.957	.943
103.	.582	.574	.565	.557	.549	136.	1.015	1.000	.985	.971	.957
103.5	.588	.579	.571	.562	.554	137.	1.030	1.015	1.000	.986	.971
104.	.593	.585	.576	.568	.560	138.	1.045	1.030	1.015	1.000	.986
104.5	.599	.590	.582	.573	.565	139.	1.060	1.045	1.029	1.015	1.000
105.	.605	.596	.587	.579	.571	140.	1.075	1.060	1.044	1.029	1.014
105.5	.611	.602	.593	.584	.576	141.	1.091	1.075	1.059	1.044	1.029
106.	.617	.607	.599	.590	.582	142.	1.106	1.090	1.074	1.059	1.044
106.5	.622	.613	.604	.596	.587	143.	1.122	1.106	1.090	1.074	1.058
107.	.628	.619	.610	.601	.593	144.	1.138	1.121	1.105	1.089	1.073
107.5	.634	.625	.616	.607	.598	145.	1.154	1.137	1.120	1.104	1.088
108.	.640	.631	.621	.612	.604	146.	1.170	1.152	1.136	1.119	1.103
108.5	.646	.636	.627	.618	.609	147.	1.186	1.168	1.151	1.135	1.118
109.	.652	.642	.633	.624	.615	148.	1.202	1.184	1.167	1.150	1.134
109.5	.658	.648	.639	.630	.621	149.	1.218	1.200	1.183	1.166	1.149
110.	.664	.654	.645	.635	.626	150.	1.235	1.216	1.199	1.181	1.165
110.5	.670	.660	.651	.641	.632	151.	1.251	1.233	1.215	1.197	1.180
111.	.676	.666	.656	.647	.638	152.	1.268	1.249	1.231	1.213	1.196
111.5	.682	.672	.662	.653	.643	153.	1.284	1.266	1.247	1.229	1.212
112.	.688	.678	.668	.659	.649	154.	1.301	1.282	1.264	1.245	1.227
112.5	.694	.684	.674	.665	.655	155.	1.318	1.299	1.280	1.262	1.243
113.	.701	.690	.680	.671	.661	156.	1.335	1.316	1.297	1.278	1.260
113.5	.707	.696	.686	.676	.667	157.	1.352	1.333	1.313	1.294	1.276
114.	.713	.703	.692	.682	.673	158.	1.370	1.350	1.330	1.311	1.292
114.5	.719	.709	.699	.688	.679	159.	1.387	1.367	1.347	1.328	1.308
115.	.726	.715	.705	.694	.685	160.	1.405	1.384	1.364	1.344	1.325
115.5	.732	.721	.711	.700	.691	161.	1.422	1.401	1.381	1.361	1.342
116.	.738	.727	.717	.707	.697	162.	1.440	1.419	1.398	1.378	1.358
116.5	.745	.734	.723	.713	.703	163.	1.458	1.436	1.416	1.395	1.375
117.	.751	.740	.729	.719	.709	164.	1.476	1.454	1.433	1.412	1.392
117.5	.758	.746	.736	.725	.715	165.	1.494	1.472	1.451	1.430	1.409
118.	.764	.753	.742	.731	.721	166.	1.512	1.490	1.468	1.447	1.426
118.5	.770	.759	.748	.737	.727	167.	1.530	1.508	1.486	1.464	1.443
119.	.777	.766	.754	.744	.733	168.	1.549	1.526	1.504	1.482	1.461
119.5	.784	.772	.761	.750	.739	169.	1.567	1.544	1.522	1.500	1.478
120.	.790	.779	.767	.756	.745	170.	1.586	1.562	1.540	1.518	1.496
121.	.803	.792	.780	.769	.758	171.	1.604	1.581	1.558	1.535	1.513
122.	.817	.805	.793	.782	.770	172.	1.623	1.599	1.576	1.553	1.531
123.	.830	.818	.806	.794	.783	173.	1.642	1.618	1.595	1.572	1.549
124.	.844	.831	.819	.807	.796	174.	1.661	1.637	1.613	1.590	1.567
125.	.857	.845	.833	.820	.809	175.	1.680	1.656	1.632	1.608	1.585
126.	.871	.858	.846	.834	.822	176.	1.700	1.675	1.650	1.627	1.603
127.	.885	.872	.859	.847	.835	177.	1.719	1.694	1.669	1.645	1.621
128.	.899	.886	.873	.860	.848	178.	1.739	1.713	1.688	1.664	1.640
129.	.913	.900	.887	.874	.861	179.	1.758	1.732	1.707	1.682	1.658

Table 18—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time 140 to 144 Seconds. Specific Gravity of Air 1.00.

Gas Time Seconds	Air Time Seconds				
	140	141	142	143	144
105.	.562	.555	.547	.539	.532
105.5	.568	.560	.552	.544	.537
106.	.573	.565	.557	.549	.542
106.5	.579	.570	.562	.555	.547
107.	.584	.576	.568	.560	.552
107.5	.590	.581	.573	.565	.557
108.	.595	.587	.578	.570	.562
108.5	.601	.592	.584	.576	.568
109.	.606	.598	.589	.581	.573
109.5	.612	.603	.595	.586	.578
110.	.617	.609	.600	.592	.584
110.5	.623	.614	.606	.597	.589
111.	.629	.620	.611	.603	.594
111.5	.634	.625	.617	.608	.600
112.	.640	.631	.622	.613	.605
112.5	.646	.637	.628	.619	.610
113.	.651	.642	.633	.624	.616
113.5	.657	.648	.639	.630	.621
114.	.663	.654	.645	.636	.627
114.5	.669	.659	.650	.641	.632
115.	.675	.665	.656	.647	.638
115.5	.681	.671	.662	.652	.643
116.	.687	.677	.667	.658	.649
116.5	.692	.683	.673	.664	.655
117.	.698	.689	.679	.669	.661
117.5	.704	.694	.685	.675	.666
118.	.710	.700	.691	.681	.671
118.5	.716	.706	.696	.687	.677
119.	.723	.712	.702	.693	.683
119.5	.729	.718	.708	.698	.689
120.	.735	.724	.714	.704	.694
121.	.747	.736	.726	.716	.706
122.	.759	.749	.738	.728	.718
123.	.772	.761	.750	.740	.730
124.	.784	.773	.763	.752	.742
125.	.797	.786	.775	.764	.754
126.	.810	.799	.787	.776	.766
127.	.823	.811	.800	.789	.778
128.	.836	.824	.813	.801	.790
129.	.849	.837	.825	.814	.803
130.	.862	.850	.838	.826	.815
131.	.876	.863	.851	.839	.828
132.	.889	.876	.864	.852	.840
133.	.903	.890	.877	.865	.853
134.	.916	.903	.890	.878	.866
135.	.930	.917	.904	.891	.879
136.	.944	.930	.917	.904	.892
137.	.958	.944	.931	.918	.905
138.	.972	.958	.944	.931	.918
139.	.986	.972	.958	.945	.932

Gas Time Seconds	Air Time Seconds				
	140	141	142	143	144
140.	1.000	.986	.972	.958	.945
141.	1.014	1.000	.986	.972	.959
142.	1.029	1.015	1.000	.986	.972
143.	1.043	1.029	1.014	1.000	.986
144.	1.058	1.043	1.028	1.014	1.000
145.	1.073	1.058	1.043	1.028	1.014
146.	1.088	1.073	1.057	1.042	1.028
147.	1.103	1.087	1.072	1.057	1.042
148.	1.118	1.102	1.086	1.071	1.056
149.	1.133	1.117	1.101	1.086	1.071
150.	1.148	1.132	1.116	1.100	1.085
151.	1.163	1.147	1.131	1.115	1.100
152.	1.179	1.162	1.146	1.130	1.114
153.	1.194	1.177	1.161	1.145	1.129
154.	1.210	1.193	1.176	1.160	1.144
155.	1.226	1.208	1.191	1.175	1.159
156.	1.242	1.224	1.207	1.190	1.174
157.	1.258	1.240	1.222	1.205	1.189
158.	1.274	1.256	1.238	1.221	1.204
159.	1.290	1.272	1.254	1.236	1.219
160.	1.306	1.288	1.270	1.252	1.235
161.	1.323	1.304	1.286	1.268	1.250
162.	1.339	1.320	1.302	1.283	1.266
163.	1.356	1.336	1.318	1.299	1.281
164.	1.372	1.353	1.334	1.315	1.297
165.	1.389	1.369	1.350	1.331	1.313
166.	1.406	1.386	1.367	1.348	1.329
167.	1.423	1.403	1.383	1.364	1.345
168.	1.440	1.420	1.400	1.380	1.361
169.	1.457	1.437	1.416	1.397	1.377
170.	1.475	1.454	1.433	1.413	1.394
171.	1.492	1.471	1.450	1.430	1.410
172.	1.509	1.488	1.467	1.447	1.427
173.	1.527	1.505	1.484	1.464	1.443
174.	1.545	1.523	1.501	1.481	1.460
175.	1.563	1.540	1.519	1.498	1.477
176.	1.580	1.558	1.536	1.515	1.494
177.	1.598	1.576	1.554	1.532	1.511
178.	1.617	1.593	1.571	1.549	1.528
179.	1.635	1.611	1.589	1.567	1.545
180.	1.653	1.630	1.607	1.585	1.562
181.	1.671	1.648	1.625	1.602	1.580
182.	1.690	1.666	1.643	1.620	1.597
183.	1.709	1.684	1.661	1.638	1.615
184.	1.728	1.703	1.679	1.656	1.633
185.	1.746	1.721	1.697	1.674	1.651
186.	1.765	1.740	1.716	1.692	1.669
187.	1.784	1.759	1.734	1.710	1.686
188.	1.803	1.778	1.753	1.728	1.704
189.	1.822	1.797	1.771	1.747	1.723

Table 19—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time **145** to **149** Seconds. Specific Gravity of Air **1.00**.

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	145	146	147	148	149		145	146	147	148	149
107.5	.550	.542	.535	.528	.521	145.	1.000	.986	.973	.960	.947
108.	.555	.547	.540	.533	.525	146.	1.014	1.000	.986	.973	.960
108.5	.560	.552	.545	.537	.530	147.	1.028	1.014	1.000	.986	.973
109.	.565	.557	.550	.542	.535	148.	1.042	1.028	1.014	1.000	.987
109.5	.570	.562	.555	.547	.540	149.	1.056	1.042	1.027	1.014	1.000
110.	.576	.568	.560	.552	.545	150.	1.070	1.056	1.041	1.027	1.013
110.5	.581	.573	.565	.557	.550	151.	1.084	1.070	1.055	1.041	1.027
111.	.586	.578	.570	.562	.555	152.	1.099	1.084	1.069	1.055	1.041
111.5	.591	.583	.575	.568	.560	153.	1.113	1.098	1.083	1.069	1.054
112.	.597	.588	.580	.573	.565	154.	1.128	1.113	1.098	1.083	1.068
112.5	.602	.594	.586	.578	.570	155.	1.143	1.127	1.112	1.097	1.082
113.	.607	.599	.591	.583	.575	156.	1.158	1.142	1.126	1.111	1.096
113.5	.613	.604	.596	.588	.580	157.	1.173	1.156	1.141	1.125	1.110
114.	.618	.610	.601	.593	.585	158.	1.188	1.171	1.155	1.140	1.124
114.5	.624	.615	.607	.599	.591	159.	1.203	1.186	1.170	1.154	1.139
115.	.629	.620	.612	.604	.596	160.	1.218	1.201	1.185	1.169	1.153
115.5	.634	.626	.617	.609	.601	161.	1.233	1.216	1.200	1.183	1.169
116.	.640	.631	.623	.614	.606	162.	1.248	1.231	1.215	1.198	1.184
116.5	.646	.637	.628	.620	.611	163.	1.264	1.246	1.230	1.213	1.199
117.	.651	.642	.633	.625	.617	164.	1.279	1.262	1.245	1.228	1.213
117.5	.657	.648	.639	.630	.622	165.	1.295	1.277	1.260	1.243	1.228
118.	.662	.653	.644	.636	.627	166.	1.311	1.293	1.275	1.258	1.243
118.5	.668	.658	.650	.641	.632	167.	1.327	1.308	1.291	1.273	1.257
119.	.674	.664	.655	.647	.638	168.	1.343	1.324	1.306	1.289	1.271
119.5	.679	.670	.661	.652	.643	169.	1.359	1.340	1.322	1.304	1.286
120.	.685	.676	.666	.657	.649	170.	1.375	1.356	1.337	1.319	1.302
121.	.696	.687	.678	.668	.660	171.	1.391	1.372	1.353	1.335	1.317
122.	.708	.698	.689	.680	.671	172.	1.407	1.388	1.369	1.351	1.333
123.	.720	.710	.700	.691	.682	173.	1.423	1.404	1.385	1.366	1.348
124.	.731	.722	.712	.702	.693	174.	1.440	1.420	1.401	1.382	1.364
125.	.743	.733	.723	.713	.704	175.	1.457	1.437	1.417	1.398	1.379
126.	.755	.745	.735	.725	.715	176.	1.473	1.453	1.433	1.414	1.395
127.	.767	.757	.746	.736	.726	177.	1.490	1.470	1.450	1.430	1.411
128.	.779	.769	.758	.748	.738	178.	1.507	1.486	1.466	1.447	1.427
129.	.791	.781	.770	.760	.750	179.	1.524	1.503	1.483	1.463	1.443
130.	.804	.793	.782	.772	.761	180.	1.541	1.520	1.499	1.479	1.459
131.	.816	.805	.794	.783	.773	181.	1.558	1.537	1.516	1.496	1.476
132.	.829	.817	.806	.795	.785	182.	1.575	1.554	1.533	1.512	1.492
133.	.841	.828	.819	.808	.797	183.	1.593	1.571	1.550	1.529	1.508
134.	.854	.842	.831	.820	.809	184.	1.610	1.588	1.567	1.546	1.525
135.	.867	.855	.843	.832	.821	185.	1.628	1.606	1.584	1.563	1.542
136.	.880	.868	.856	.844	.833	186.	1.646	1.623	1.601	1.579	1.558
137.	.893	.881	.869	.857	.845	187.	1.663	1.641	1.618	1.596	1.575
138.	.906	.893	.881	.869	.858	188.	1.681	1.658	1.635	1.614	1.592
139.	.919	.906	.894	.882	.870	189.	1.699	1.676	1.653	1.631	1.609
140.	.932	.919	.907	.895	.883	190.	1.717	1.694	1.671	1.648	1.626
141.	.946	.933	.920	.908	.895	191.	1.735	1.711	1.688	1.666	1.643
142.	.959	.946	.933	.921	.908	192.	1.753	1.729	1.706	1.683	1.660
143.	.973	.959	.946	.934	.921	193.	1.772	1.747	1.724	1.701	1.678
144.	.986	.973	.960	.947	.934	194.	1.790	1.766	1.742	1.718	1.695

Table 20—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time **150** to **154** Seconds. Specific Gravity of Air 1.00.

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	150	151	152	153	154		150	151	152	153	154
110.	.538	.531	.524	.517	.510	150.	1.000	.987	.974	.961	.949
110.5	.543	.536	.528	.522	.515	151.	1.013	1.000	.987	.974	.961
111.	.548	.540	.533	.526	.520	152.	1.027	1.013	1.000	.987	.974
111.5	.553	.545	.538	.531	.524	153.	1.040	1.027	1.013	1.000	.987
112.	.558	.550	.543	.536	.529	154.	1.054	1.040	1.026	1.013	1.000
112.5	.562	.555	.548	.541	.534	155.	1.068	1.054	1.040	1.026	1.013
113.	.568	.560	.553	.545	.538	156.	1.082	1.067	1.053	1.040	1.026
113.5	.573	.565	.558	.550	.543	157.	1.096	1.081	1.067	1.053	1.039
114.	.578	.570	.562	.555	.548	158.	1.110	1.095	1.081	1.066	1.053
114.5	.583	.575	.567	.560	.553	159.	1.124	1.109	1.094	1.080	1.066
115.	.588	.580	.572	.565	.558	160.	1.138	1.123	1.108	1.094	1.079
115.5	.593	.585	.577	.570	.563	161.	1.152	1.137	1.122	1.107	1.093
116.	.598	.590	.582	.575	.567	162.	1.166	1.151	1.136	1.121	1.107
116.5	.603	.595	.587	.580	.572	163.	1.181	1.165	1.150	1.135	1.120
117.	.608	.600	.593	.585	.577	164.	1.195	1.180	1.164	1.149	1.134
117.5	.614	.606	.598	.590	.582	165.	1.210	1.194	1.178	1.163	1.148
118.	.619	.611	.603	.595	.587	166.	1.225	1.209	1.193	1.177	1.162
118.5	.624	.616	.608	.600	.592	167.	1.240	1.223	1.207	1.191	1.176
119.	.629	.621	.613	.605	.597	168.	1.254	1.238	1.222	1.206	1.190
119.5	.635	.626	.618	.610	.602	169.	1.269	1.253	1.236	1.220	1.204
120.	.640	.632	.623	.615	.607	170.	1.284	1.267	1.251	1.235	1.219
121.	.651	.642	.634	.625	.617	171.	1.300	1.282	1.266	1.249	1.233
122.	.661	.653	.644	.636	.628	172.	1.315	1.297	1.280	1.264	1.247
123.	.672	.664	.655	.646	.638	173.	1.330	1.313	1.295	1.279	1.262
124.	.683	.674	.665	.657	.648	174.	1.346	1.328	1.310	1.293	1.277
125.	.694	.685	.676	.667	.659	175.	1.361	1.343	1.326	1.308	1.291
126.	.706	.696	.687	.678	.669	176.	1.377	1.359	1.341	1.323	1.306
127.	.717	.707	.698	.689	.680	177.	1.392	1.374	1.356	1.338	1.321
128.	.728	.719	.708	.700	.691	178.	1.408	1.390	1.371	1.353	1.336
129.	.740	.730	.720	.711	.702	179.	1.424	1.405	1.387	1.369	1.351
130.	.751	.741	.731	.722	.713	180.	1.440	1.421	1.402	1.384	1.366
131.	.763	.753	.743	.733	.724	181.	1.456	1.437	1.418	1.400	1.381
132.	.774	.764	.754	.744	.735	182.	1.472	1.453	1.434	1.415	1.397
133.	.786	.776	.766	.756	.746	183.	1.488	1.469	1.449	1.431	1.412
134.	.798	.788	.777	.767	.757	184.	1.505	1.485	1.465	1.446	1.428
135.	.810	.799	.789	.779	.768	185.	1.521	1.501	1.481	1.462	1.443
136.	.822	.811	.801	.790	.780	186.	1.537	1.517	1.497	1.478	1.459
137.	.834	.823	.812	.802	.791	187.	1.554	1.534	1.514	1.494	1.474
138.	.846	.835	.824	.814	.803	188.	1.571	1.550	1.530	1.510	1.490
139.	.859	.847	.836	.825	.815	189.	1.588	1.567	1.546	1.526	1.506
140.	.871	.860	.848	.837	.826	190.	1.604	1.583	1.563	1.542	1.522
141.	.884	.872	.861	.849	.838	191.	1.621	1.600	1.579	1.558	1.538
142.	.896	.884	.873	.861	.850	192.	1.638	1.617	1.596	1.575	1.554
143.	.909	.897	.885	.874	.862	193.	1.656	1.634	1.612	1.591	1.571
144.	.922	.909	.898	.886	.874	194.	1.673	1.651	1.629	1.608	1.587
145.	.934	.922	.910	.898	.887	195.	1.690	1.668	1.646	1.624	1.603
146.	.947	.935	.923	.911	.899	196.	1.707	1.685	1.663	1.641	1.620
147.	.961	.948	.935	.923	.911	197.	1.725	1.702	1.680	1.658	1.736
148.	.974	.961	.948	.936	.924	198.	1.742	1.719	1.697	1.675	1.653
149.	.987	.974	.961	.948	.936	199.	1.760	1.737	1.714	1.692	1.670

Table 21—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time **155** to **159** Seconds. Specific Gravity of Air **1.00**.

Gas Time Seconds	Air Time Seconds				
	155	156	157	158	159
115.	.550	.543	.537	.530	.523
115.5	.555	.548	.541	.534	.528
116.	.560	.553	.546	.539	.532
116.5	.565	.558	.551	.544	.537
117.	.570	.562	.555	.548	.541
117.5	.575	.567	.560	.553	.546
118.	.580	.572	.565	.558	.551
118.5	.584	.577	.570	.562	.555
119.	.589	.582	.574	.567	.560
119.5	.594	.587	.579	.572	.565
120.	.599	.592	.584	.577	.570
121.	.609	.602	.594	.586	.579
122.	.620	.612	.604	.596	.589
123.	.630	.622	.614	.606	.598
124.	.640	.632	.624	.616	.608
125.	.650	.642	.634	.626	.618
126.	.661	.652	.644	.636	.628
127.	.671	.663	.654	.646	.638
128.	.682	.673	.665	.656	.648
129.	.693	.684	.675	.667	.658
130.	.703	.694	.686	.677	.668
131.	.714	.705	.696	.687	.679
132.	.725	.716	.707	.698	.689
133.	.736	.727	.718	.709	.700
134.	.747	.738	.728	.719	.710
135.	.759	.749	.739	.730	.721
136.	.770	.760	.750	.741	.732
137.	.781	.771	.761	.752	.742
138.	.793	.783	.773	.763	.753
139.	.804	.794	.784	.774	.764
140.	.816	.805	.795	.785	.775
141.	.828	.817	.807	.796	.786
142.	.839	.829	.818	.808	.798
143.	.851	.840	.830	.819	.809
144.	.863	.852	.841	.831	.820
145.	.875	.864	.853	.842	.832
146.	.887	.876	.865	.854	.843
147.	.899	.888	.877	.865	.855
148.	.912	.900	.889	.877	.866
149.	.924	.912	.901	.889	.878
150.	.936	.925	.913	.901	.890
151.	.949	.937	.925	.913	.902
152.	.962	.949	.937	.925	.914
153.	.974	.962	.950	.938	.926
154.	.987	.975	.962	.950	.938
155.	1.000	.987	.975	.962	.950
156.	1.013	1.000	.987	.975	.963
157.	1.026	1.013	1.000	.987	.975
158.	1.039	1.026	1.013	1.000	.987
159.	1.052	1.039	1.026	1.013	1.000

Gas Time Seconds	Air Time Seconds				
	155	156	157	158	159
160.	1.066	1.052	1.039	1.025	1.013
161.	1.079	1.065	1.052	1.038	1.025
162.	1.092	1.078	1.065	1.051	1.038
163.	1.106	1.092	1.078	1.064	1.051
164.	1.120	1.105	1.091	1.077	1.064
165.	1.133	1.119	1.104	1.091	1.077
166.	1.147	1.132	1.118	1.104	1.090
167.	1.161	1.146	1.131	1.117	1.103
168.	1.175	1.160	1.145	1.131	1.116
169.	1.189	1.174	1.159	1.144	1.130
170.	1.203	1.188	1.172	1.158	1.143
171.	1.217	1.202	1.186	1.171	1.157
172.	1.231	1.216	1.200	1.185	1.170
173.	1.246	1.230	1.214	1.199	1.184
174.	1.260	1.244	1.228	1.213	1.198
175.	1.275	1.258	1.242	1.227	1.211
176.	1.289	1.273	1.257	1.241	1.225
177.	1.304	1.287	1.271	1.255	1.239
178.	1.319	1.302	1.285	1.269	1.253
179.	1.334	1.317	1.300	1.283	1.267
180.	1.349	1.331	1.314	1.298	1.282
181.	1.364	1.346	1.329	1.312	1.296
182.	1.379	1.361	1.344	1.327	1.310
183.	1.394	1.376	1.359	1.341	1.325
184.	1.409	1.391	1.374	1.356	1.339
185.	1.425	1.406	1.388	1.371	1.354
186.	1.440	1.422	1.404	1.386	1.368
187.	1.455	1.437	1.419	1.401	1.383
188.	1.471	1.452	1.434	1.416	1.398
189.	1.487	1.468	1.449	1.431	1.413
190.	1.502	1.483	1.465	1.446	1.428
191.	1.518	1.499	1.480	1.461	1.443
192.	1.534	1.515	1.496	1.477	1.458
193.	1.550	1.531	1.511	1.492	1.473
194.	1.567	1.547	1.527	1.508	1.489
195.	1.583	1.563	1.543	1.523	1.504
196.	1.599	1.579	1.559	1.539	1.520
197.	1.615	1.595	1.574	1.555	1.535
198.	1.632	1.611	1.590	1.571	1.551
199.	1.648	1.627	1.607	1.587	1.566
200.	1.664	1.644	1.623	1.602	1.582
201.	1.681	1.660	1.639	1.618	1.598
202.	1.698	1.677	1.655	1.634	1.614
203.	1.715	1.693	1.672	1.651	1.630
204.	1.732	1.710	1.688	1.667	1.646
205.	1.749	1.727	1.705	1.683	1.662
206.	1.766	1.744	1.722	1.700	1.679
207.	1.784	1.761	1.738	1.716	1.695
208.	1.801	1.778	1.755	1.733	1.711
209.	1.818	1.795	1.772	1.750	1.728

Table 22—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time 160 to 164 Seconds. Specific Gravity of Air **1.00.**

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	160	161	162	163	164		160	161	162	163	164
117.5	.539	.533	.526	.520	.513	165.	1.063	1.050	1.037	1.025	1.012
118.	.544	.537	.531	.524	.518	166.	1.076	1.063	1.050	1.037	1.025
118.5	.549	.542	.535	.529	.522	167.	1.089	1.076	1.063	1.050	1.037
119.	.553	.546	.540	.533	.527	168.	1.103	1.089	1.075	1.062	1.049
119.5	.558	.551	.544	.537	.531	169.	1.116	1.102	1.088	1.075	1.062
120.	.562	.556	.549	.542	.535	170.	1.129	1.115	1.101	1.088	1.075
121.	.572	.565	.558	.551	.544	171.	1.142	1.128	1.114	1.101	1.087
122.	.581	.574	.567	.560	.553	172.	1.156	1.141	1.127	1.113	1.100
123.	.591	.584	.576	.569	.562	173.	1.169	1.155	1.140	1.126	1.113
124.	.601	.593	.586	.579	.572	174.	1.183	1.168	1.154	1.140	1.126
125.	.610	.603	.595	.588	.581	175.	1.196	1.181	1.167	1.153	1.139
126.	.620	.612	.605	.598	.590	176.	1.210	1.195	1.180	1.166	1.152
127.	.630	.622	.615	.607	.600	177.	1.224	1.209	1.194	1.179	1.165
128.	.640	.632	.624	.617	.609	178.	1.238	1.222	1.207	1.193	1.178
129.	.650	.642	.634	.626	.619	179.	1.252	1.236	1.221	1.206	1.191
130.	.660	.652	.644	.636	.628	180.	1.266	1.250	1.235	1.219	1.205
131.	.670	.662	.654	.646	.638	181.	1.280	1.264	1.248	1.233	1.218
132.	.681	.672	.664	.656	.648	182.	1.294	1.278	1.262	1.247	1.232
133.	.691	.682	.674	.666	.658	183.	1.308	1.292	1.276	1.260	1.245
134.	.701	.693	.684	.676	.668	184.	1.323	1.306	1.290	1.274	1.259
135.	.712	.703	.694	.686	.678	185.	1.337	1.320	1.304	1.288	1.272
136.	.722	.714	.705	.696	.688	186.	1.351	1.335	1.318	1.302	1.286
137.	.733	.724	.715	.706	.698	187.	1.366	1.349	1.332	1.316	1.300
138.	.744	.735	.726	.717	.708	188.	1.381	1.364	1.347	1.330	1.314
139.	.755	.745	.736	.727	.718	189.	1.395	1.378	1.361	1.344	1.328
140.	.766	.756	.747	.738	.729	190.	1.410	1.393	1.376	1.359	1.342
141.	.777	.767	.758	.748	.739	191.	1.425	1.407	1.390	1.373	1.356
142.	.788	.778	.768	.759	.750	192.	1.440	1.422	1.405	1.387	1.371
143.	.799	.789	.779	.770	.760	193.	1.455	1.437	1.419	1.402	1.385
144.	.810	.800	.790	.780	.771	194.	1.470	1.452	1.434	1.417	1.399
145.	.821	.811	.801	.791	.782	195.	1.485	1.467	1.449	1.431	1.414
146.	.833	.822	.812	.802	.793	196.	1.501	1.482	1.464	1.446	1.428
147.	.844	.833	.823	.813	.803	197.	1.516	1.497	1.479	1.461	1.443
148.	.856	.845	.835	.824	.814	198.	1.531	1.512	1.494	1.476	1.458
149.	.867	.856	.846	.836	.825	199.	1.547	1.528	1.509	1.491	1.472
150.	.879	.868	.857	.847	.837	200.	1.563	1.543	1.524	1.506	1.487
151.	.891	.880	.869	.858	.848	201.	1.578	1.559	1.539	1.521	1.502
152.	.902	.891	.880	.870	.859	202.	1.594	1.574	1.555	1.536	1.517
153.	.914	.903	.892	.881	.870	203.	1.610	1.590	1.570	1.551	1.532
154.	.926	.915	.904	.893	.882	204.	1.626	1.606	1.586	1.566	1.547
155.	.939	.927	.915	.904	.893	205.	1.642	1.621	1.601	1.582	1.562
156.	.951	.939	.928	.916	.905	206.	1.658	1.637	1.617	1.597	1.578
157.	.963	.951	.939	.928	.916	207.	1.674	1.653	1.633	1.613	1.593
158.	.975	.963	.951	.940	.928	208.	1.690	1.669	1.648	1.628	1.608
159.	.988	.975	.963	.952	.940	209.	1.706	1.685	1.664	1.644	1.624
160.	1.000	.988	.975	.964	.952	210.	1.723	1.701	1.680	1.660	1.640
161.	1.013	1.000	.988	.976	.964	211.	1.739	1.718	1.696	1.676	1.655
162.	1.025	1.013	1.000	.988	.976	212.	1.755	1.734	1.712	1.692	1.671
163.	1.038	1.025	1.012	1.000	.988	213.	1.772	1.750	1.729	1.708	1.687
164.	1.051	1.038	1.025	1.012	1.000	214.	1.789	1.767	1.745	1.724	1.703

Table 23—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time **165** to **169** Seconds. Specific Gravity of Air 1.00.

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	165	166	167	168	169		165	166	167	168	169
120.	.529	.523	.516	.510	.504	170.	1.062	1.049	1.036	1.024	1.012
121.	.538	.531	.525	.519	.513	171.	1.074	1.061	1.048	1.036	1.024
122.	.547	.540	.534	.527	.521	172.	1.087	1.074	1.061	1.048	1.036
123.	.556	.549	.542	.536	.530	173.	1.099	1.086	1.073	1.060	1.048
124.	.565	.558	.551	.545	.538	174.	1.112	1.099	1.086	1.073	1.060
125.	.574	.567	.560	.554	.547	175.	1.125	1.111	1.098	1.085	1.072
126.	.583	.576	.569	.562	.556	176.	1.138	1.124	1.111	1.098	1.085
127.	.592	.585	.578	.571	.565	177.	1.151	1.137	1.123	1.110	1.097
128.	.602	.595	.587	.581	.574	178.	1.164	1.150	1.136	1.123	1.109
129.	.611	.604	.597	.590	.583	179.	1.177	1.163	1.149	1.135	1.122
130.	.621	.613	.606	.599	.592	180.	1.190	1.176	1.162	1.148	1.134
131.	.630	.623	.615	.608	.601	181.	1.203	1.189	1.175	1.161	1.147
132.	.640	.632	.625	.617	.610	182.	1.217	1.202	1.188	1.174	1.160
133.	.650	.642	.634	.627	.619	183.	1.230	1.215	1.201	1.187	1.173
134.	.660	.652	.644	.636	.629	184.	1.244	1.229	1.214	1.199	1.185
135.	.669	.661	.653	.646	.638	185.	1.258	1.242	1.227	1.212	1.198
136.	.679	.671	.663	.655	.648	186.	1.271	1.255	1.240	1.226	1.211
137.	.689	.681	.673	.665	.657	187.	1.284	1.269	1.254	1.239	1.224
138.	.700	.691	.683	.675	.667	188.	1.298	1.283	1.267	1.252	1.237
139.	.710	.701	.693	.685	.677	189.	1.312	1.296	1.281	1.266	1.251
140.	.720	.711	.703	.694	.686	190.	1.326	1.310	1.294	1.279	1.264
141.	.730	.722	.713	.704	.696	191.	1.340	1.324	1.308	1.293	1.277
142.	.741	.732	.723	.714	.706	192.	1.354	1.338	1.322	1.306	1.291
143.	.751	.742	.733	.725	.716	193.	1.368	1.352	1.336	1.320	1.304
144.	.762	.753	.744	.735	.726	194.	1.382	1.366	1.349	1.333	1.318
145.	.772	.763	.754	.745	.736	195.	1.397	1.380	1.363	1.347	1.331
146.	.783	.774	.764	.755	.746	196.	1.411	1.394	1.377	1.361	1.345
147.	.794	.784	.775	.766	.756	197.	1.425	1.408	1.392	1.375	1.359
148.	.805	.795	.785	.776	.767	198.	1.440	1.423	1.406	1.389	1.373
149.	.815	.806	.796	.787	.777	199.	1.455	1.437	1.420	1.403	1.387
150.	.826	.817	.807	.797	.788	200.	1.469	1.452	1.434	1.417	1.401
151.	.838	.827	.818	.808	.798	201.	1.484	1.466	1.449	1.431	1.415
152.	.849	.838	.828	.819	.809	202.	1.499	1.480	1.463	1.446	1.429
153.	.860	.850	.839	.829	.820	203.	1.514	1.495	1.478	1.460	1.443
154.	.871	.861	.850	.840	.830	204.	1.529	1.510	1.493	1.474	1.457
155.	.882	.872	.861	.851	.841	205.	1.544	1.525	1.507	1.489	1.471
156.	.894	.883	.873	.862	.852	206.	1.559	1.540	1.522	1.504	1.486
157.	.905	.895	.884	.873	.863	207.	1.574	1.555	1.536	1.518	1.500
158.	.917	.906	.895	.884	.874	208.	1.589	1.570	1.551	1.533	1.515
159	.929	.917	.906	.896	.885	209.	1.604	1.585	1.566	1.548	1.529
160.	.940	.929	.918	.907	.896	210.	1.620	1.600	1.581	1.563	1.544
161.	.952	.941	.929	.918	.908	211.	1.635	1.616	1.596	1.577	1.559
162.	.964	.952	.941	.930	.919	212.	1.651	1.631	1.611	1.592	1.573
163.	.976	.964	.953	.941	.930	213.	1.666	1.646	1.627	1.607	1.589
164.	.988	.976	.965	.953	.942	214.	1.682	1.662	1.642	1.623	1.604
165.	1.000	.988	.976	.965	.953	215.	1.698	1.678	1.657	1.638	1.619
166.	1.012	1.000	.988	.976	.965	216.	1.714	1.693	1.673	1.653	1.634
167.	1.024	1.012	1.000	.988	.976	217.	1.730	1.709	1.688	1.668	1.649
168.	1.037	1.024	1.012	1.000	.988	218.	1.746	1.725	1.704	1.684	1.664
169.	1.049	1.036	1.024	1.012	1.000	219.	1.762	1.741	1.720	1.699	1.679

Table 24—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time 170 to 174 Seconds. Specific Gravity of Air **1.00**

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	170	171	172	173	174		170	171	172	173	174
125.	.541	.534	.528	.522	.516	175.	1.060	1.047	1.035	1.023	1.012
126.	.549	.543	.537	.530	.524	176.	1.072	1.059	1.047	1.035	1.023
127.	.558	.552	.545	.539	.533	177.	1.084	1.071	1.059	1.047	1.035
128.	.567	.560	.554	.547	.541	178.	1.096	1.084	1.071	1.059	1.047
129.	.576	.569	.562	.556	.550	179.	1.108	1.096	1.083	1.071	1.058
130.	.585	.578	.571	.565	.558	180.	1.121	1.108	1.095	1.083	1.070
131.	.594	.587	.580	.573	.567	181.	1.134	1.120	1.107	1.095	1.082
132.	.603	.596	.589	.582	.575	182.	1.146	1.133	1.120	1.107	1.094
133.	.612	.605	.598	.591	.584	183.	1.159	1.145	1.132	1.119	1.106
134.	.621	.614	.607	.600	.595	184.	1.171	1.158	1.144	1.131	1.118
135.	.631	.623	.616	.609	.603	185.	1.184	1.170	1.157	1.144	1.130
136.	.640	.633	.625	.618	.611	186.	1.197	1.183	1.169	1.156	1.143
137.	.649	.642	.634	.627	.620	187.	1.210	1.196	1.182	1.168	1.155
138.	.659	.651	.644	.636	.629	188.	1.223	1.209	1.195	1.181	1.167
139.	.669	.660	.653	.646	.638	189.	1.236	1.222	1.207	1.194	1.180
140.	.678	.670	.663	.655	.647	190.	1.249	1.235	1.220	1.206	1.192
141.	.688	.680	.672	.664	.657	191.	1.262	1.248	1.233	1.219	1.205
142.	.698	.690	.682	.674	.666	192.	1.276	1.261	1.246	1.232	1.218
143.	.708	.699	.691	.683	.675	193.	1.289	1.274	1.260	1.245	1.230
144.	.718	.709	.701	.693	.685	194.	1.302	1.287	1.272	1.258	1.243
145.	.728	.719	.711	.703	.694	195.	1.316	1.300	1.285	1.271	1.256
146.	.738	.729	.721	.712	.704	196.	1.329	1.314	1.299	1.284	1.269
147.	.748	.739	.731	.722	.714	197.	1.343	1.327	1.312	1.297	1.282
148.	.758	.749	.741	.732	.723	198.	1.357	1.341	1.325	1.310	1.295
149.	.768	.759	.751	.742	.733	199.	1.370	1.354	1.339	1.323	1.308
150.	.779	.769	.761	.752	.743	200.	1.384	1.368	1.352	1.336	1.321
151.	.789	.780	.771	.762	.753	201.	1.398	1.382	1.366	1.350	1.334
152.	.799	.790	.781	.772	.763	202.	1.412	1.395	1.379	1.363	1.348
153.	.810	.801	.791	.782	.773	203.	1.426	1.409	1.393	1.377	1.361
154.	.821	.811	.802	.792	.783	204.	1.440	1.423	1.408	1.391	1.376
155.	.831	.822	.812	.803	.794	205.	1.454	1.437	1.421	1.404	1.388
156.	.842	.832	.823	.813	.804	206.	1.469	1.451	1.435	1.418	1.402
157.	.853	.843	.833	.824	.814	207.	1.483	1.465	1.449	1.432	1.415
158.	.864	.854	.844	.834	.825	208.	1.497	1.480	1.463	1.446	1.429
159.	.875	.865	.855	.845	.835	209.	1.511	1.494	1.477	1.460	1.443
160.	.886	.875	.865	.855	.846	210.	1.526	1.508	1.491	1.474	1.457
161.	.897	.886	.876	.866	.856	211.	1.541	1.523	1.505	1.488	1.470
162.	.908	.898	.887	.877	.867	212.	1.555	1.537	1.519	1.502	1.484
163.	.919	.909	.898	.888	.878	213.	1.570	1.552	1.534	1.516	1.499
164.	.931	.920	.909	.899	.888	214.	1.585	1.566	1.548	1.530	1.513
165.	.942	.931	.920	.910	.899	215.	1.599	1.581	1.563	1.545	1.527
166.	.953	.942	.931	.921	.910	216.	1.614	1.596	1.577	1.559	1.541
167.	.965	.954	.943	.932	.921	217.	1.629	1.610	1.592	1.573	1.555
168.	.977	.965	.954	.943	.932	218.	1.644	1.625	1.606	1.588	1.570
169.	.988	.977	.965	.954	.943	219.	1.660	1.640	1.621	1.603	1.584
170.	1.000	.988	.977	.966	.955	220.	1.675	1.655	1.636	1.617	1.599
171.	1.012	1.000	.988	.977	.966	221.	1.690	1.670	1.651	1.632	1.613
172.	1.024	1.012	1.000	.988	.977	222.	1.705	1.685	1.666	1.647	1.628
173.	1.036	1.024	1.012	1.000	.989	223.	1.721	1.700	1.681	1.662	1.643
174.	1.048	1.035	1.023	1.012	1.000	224.	1.736	1.716	1.696	1.677	1.657

Table 25—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time **175** to **179** Seconds. Specific Gravity of Air **1.00**.

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	175	176	177	178	179		175	176	177	178	179
130.	.552	.546	.539	.533	.527	180.	1.058	1.046	1.034	1.023	1.011
131.	.560	.554	.548	.542	.536	181.	1.070	1.058	1.046	1.034	1.022
132.	.569	.562	.556	.550	.544	182.	1.082	1.069	1.057	1.045	1.034
133.	.578	.571	.565	.558	.552	183.	1.094	1.081	1.069	1.057	1.045
134.	.586	.580	.573	.567	.560	184.	1.106	1.093	1.081	1.069	1.057
135.	.595	.588	.582	.575	.569	185.	1.118	1.105	1.092	1.080	1.068
136.	.604	.597	.590	.584	.577	186.	1.130	1.117	1.104	1.092	1.080
137.	.613	.607	.599	.592	.586	187.	1.142	1.129	1.116	1.104	1.092
138.	.622	.615	.608	.601	.594	188.	1.154	1.141	1.128	1.116	1.103
139.	.631	.624	.617	.610	.603	189.	1.166	1.153	1.140	1.127	1.115
140.	.640	.633	.626	.619	.612	190.	1.179	1.165	1.152	1.139	1.127
141.	.649	.642	.635	.627	.620	191.	1.191	1.178	1.164	1.151	1.139
142.	.658	.651	.644	.636	.629	192.	1.204	1.190	1.177	1.163	1.151
143.	.668	.660	.653	.645	.638	193.	1.216	1.203	1.189	1.176	1.163
144.	.677	.669	.662	.654	.647	194.	1.229	1.215	1.201	1.188	1.175
145.	.687	.679	.671	.664	.656	195.	1.242	1.228	1.214	1.200	1.187
146.	.696	.688	.680	.673	.665	196.	1.254	1.240	1.226	1.212	1.199
147.	.708	.698	.690	.682	.674	197.	1.267	1.253	1.239	1.225	1.211
148.	.715	.707	.699	.691	.684	198.	1.280	1.266	1.251	1.237	1.224
149.	.725	.717	.709	.701	.693	199.	1.293	1.278	1.264	1.250	1.236
150.	.735	.726	.718	.710	.702	200.	1.306	1.291	1.277	1.262	1.248
151.	.745	.736	.728	.720	.712	201.	1.319	1.304	1.290	1.275	1.261
152.	.754	.746	.737	.729	.721	202.	1.332	1.317	1.302	1.288	1.273
153.	.764	.756	.747	.739	.731	203.	1.346	1.330	1.315	1.301	1.286
154.	.774	.766	.757	.749	.740	204.	1.359	1.343	1.328	1.313	1.299
155.	.784	.776	.767	.758	.750	205.	1.372	1.357	1.341	1.326	1.312
156.	.795	.786	.777	.768	.760	206.	1.386	1.370	1.355	1.339	1.324
157.	.805	.796	.787	.778	.770	207.	1.399	1.383	1.368	1.352	1.337
158.	.815	.806	.797	.788	.779	208.	1.413	1.397	1.381	1.365	1.350
159.	.826	.816	.807	.798	.789	209	1.426	1.410	1.394	1.379	1.363
160.	.836	.826	.817	.808	.799	210.	1.440	1.424	1.408	1.392	1.376
161.	.846	.837	.827	.818	.809	211.	1.454	1.437	1.421	1.405	1.389
162.	.857	.847	.838	.828	.819	212.	1.467	1.451	1.434	1.419	1.403
163.	.868	.858	.848	.838	.829	213.	1.481	1.465	1.448	1.432	1.416
164.	.878	.868	.859	.849	.839	214.	1.495	1.478	1.462	1.445	1.429
165.	.889	.879	.869	.859	.850	215.	1.509	1.492	1.475	1.459	1.443
166.	.900	.890	.880	.870	.860	216.	1.524	1.506	1.489	1.473	1.456
167.	.911	.900	.890	.880	.870	217.	1.538	1.520	1.503	1.486	1.470
168.	.922	.911	.901	.891	.881	218.	1.552	1.534	1.517	1.500	1.483
169.	.933	.922	.912	.901	.891	219.	1.566	1.548	1.531	1.514	1.497
170.	.944	.933	.922	.912	.902	220.	1.580	1.562	1.545	1.528	1.511
171.	.955	.944	.933	.923	.913	221.	1.595	1.577	1.559	1.542	1.524
172.	.966	.955	.944	.934	.923	222.	1.609	1.591	1.573	1.556	1.538
173.	.977	.966	.955	.945	.934	223.	1.624	1.605	1.587	1.570	1.552
174.	.989	.977	.966	.956	.945	224.	1.639	1.620	1.602	1.584	1.566
175.	1.000	.989	.978	.967	.956	225.	1.653	1.634	1.616	1.598	1.580
176.	1.011	1.000	.989	.978	.967	226.	1.668	1.649	1.630	1.612	1.594
177.	1.023	1.011	1.000	.989	.978	227.	1.683	1.664	1.645	1.626	1.608
178.	1.035	1.023	1.011	1.000	.989	228.	1.697	1.678	1.659	1.641	1.622
179.	1.046	1.034	1.023	1.011	1.000	229.	1.712	1.693	1.674	1.655	1.637

Table 26—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time 180 to 184 Seconds. Specific Gravity of Air 1.00.

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	180	181	182	183	184		180	181	182	183	184
135.	.562	.556	.550	.544	.538	185.	1.056	1.045	1.033	1.022	1.011
136.	.571	.565	.558	.552	.546	186.	1.068	1.056	1.044	1.033	1.022
137.	.579	.573	.567	.560	.554	187.	1.079	1.067	1.056	1.044	1.033
138.	.588	.581	.575	.569	.562	188.	1.091	1.079	1.067	1.056	1.044
139.	.596	.590	.583	.577	.571	189.	1.103	1.090	1.078	1.067	1.055
140.	.605	.598	.592	.585	.579	190.	1.114	1.102	1.090	1.078	1.066
141.	.614	.607	.600	.594	.587	191.	1.126	1.114	1.101	1.089	1.078
142.	.622	.616	.609	.602	.596	192.	1.138	1.125	1.113	1.101	1.089
143.	.631	.624	.617	.611	.604	193.	1.150	1.137	1.125	1.112	1.100
144.	.640	.633	.626	.619	.612	194.	1.162	1.149	1.136	1.124	1.112
145.	.649	.642	.635	.628	.621	195.	1.174	1.161	1.148	1.135	1.123
146.	.658	.651	.644	.637	.630	196.	1.186	1.173	1.160	1.147	1.135
147.	.667	.660	.652	.645	.638	197.	1.198	1.185	1.172	1.159	1.146
148.	.676	.669	.661	.654	.647	198.	1.210	1.197	1.184	1.171	1.158
149.	.685	.678	.670	.663	.656	199.	1.222	1.209	1.196	1.183	1.170
150.	.694	.687	.679	.672	.665	200.	1.235	1.221	1.208	1.194	1.181
151.	.704	.696	.688	.681	.673	201.	1.247	1.233	1.220	1.206	1.193
152.	.713	.705	.698	.690	.682	202.	1.259	1.246	1.232	1.218	1.205
153.	.723	.715	.707	.699	.691	203.	1.272	1.258	1.244	1.231	1.217
154.	.732	.724	.716	.708	.700	204.	1.285	1.270	1.257	1.243	1.229
155.	.742	.733	.725	.718	.710	205.	1.297	1.283	1.269	1.255	1.241
156.	.751	.743	.735	.727	.719	206.	1.310	1.295	1.281	1.267	1.254
157.	.761	.752	.744	.736	.728	207.	1.323	1.308	1.294	1.280	1.266
158.	.770	.761	.754	.745	.737	208.	1.335	1.321	1.306	1.292	1.278
159.	.780	.772	.763	.755	.747	209.	1.348	1.333	1.319	1.304	1.290
160.	.790	.781	.773	.764	.756	210.	1.361	1.346	1.331	1.317	1.303
161.	.800	.791	.783	.774	.766	211.	1.374	1.359	1.344	1.329	1.315
162.	.810	.801	.792	.784	.775	212.	1.387	1.372	1.357	1.342	1.327
163.	.820	.811	.802	.793	.785	213.	1.400	1.385	1.370	1.355	1.340
164.	.830	.821	.812	.803	.794	214.	1.414	1.398	1.383	1.368	1.353
165.	.840	.831	.822	.813	.804	215.	1.427	1.411	1.396	1.380	1.365
166.	.850	.841	.832	.823	.814	216.	1.440	1.424	1.409	1.393	1.378
167.	.861	.851	.842	.833	.824	217.	1.453	1.437	1.422	1.406	1.391
168.	.871	.862	.852	.843	.834	218.	1.467	1.451	1.435	1.419	1.404
169.	.882	.872	.862	.853	.843	219.	1.480	1.464	1.448	1.432	1.417
170.	.892	.882	.872	.863	.854	220.	1.494	1.477	1.461	1.445	1.430
171.	.903	.893	.883	.873	.864	221.	1.507	1.491	1.474	1.458	1.443
172.	.913	.903	.893	.883	.874	222.	1.521	1.504	1.488	1.472	1.456
173.	.924	.914	.904	.894	.884	223.	1.535	1.518	1.501	1.485	1.469
174.	.934	.924	.914	.904	.894	224.	1.549	1.532	1.515	1.498	1.482
175.	.945	.935	.925	.914	.905	225.	1.562	1.545	1.528	1.512	1.495
176.	.956	.946	.935	.925	.915	226.	1.576	1.559	1.542	1.525	1.509
177.	.967	.956	.946	.936	.925	227.	1.590	1.573	1.556	1.539	1.522
178.	.978	.967	.957	.946	.936	228.	1.604	1.587	1.569	1.552	1.535
179.	.989	.978	.967	.957	.946	229.	1.619	1.601	1.583	1.566	1.549
180.	1.000	.989	.978	.967	.957	230.	1.633	1.615	1.597	1.580	1.563
181.	1.011	1.000	.989	.978	.968	231.	1.647	1.629	1.611	1.593	1.576
182.	1.022	1.011	1.000	.989	.978	232.	1.661	1.643	1.625	1.607	1.590
183.	1.034	1.022	1.011	1.000	.989	233.	1.676	1.657	1.639	1.621	1.604
184.	1.045	1.033	1.022	1.011	1.000	234.	1.690	1.671	1.653	1.635	1.617

Table 27—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time **185** to **189** Seconds. Specific Gravity of Air **1.00**.

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	185	186	187	188	189		185	186	187	188	189
135.	.532	.527	.521	.516	.510	190.	1.055	1.043	1.032	1.021	1.011
136.	.540	.535	.529	.523	.518	191.	1.066	1.054	1.043	1.032	1.021
137.	.548	.543	.537	.531	.525	192.	1.077	1.066	1.054	1.043	1.032
138.	.556	.550	.545	.539	.533	193.	1.088	1.077	1.065	1.054	1.043
139.	.565	.558	.553	.547	.541	194.	1.100	1.088	1.076	1.065	1.054
140.	.573	.567	.561	.555	.549	195.	1.111	1.099	1.087	1.076	1.064
141.	.581	.575	.569	.562	.557	196.	1.122	1.110	1.099	1.087	1.075
142.	.589	.583	.577	.571	.564	197.	1.134	1.122	1.110	1.098	1.086
143.	.597	.591	.585	.579	.572	198.	1.145	1.133	1.121	1.109	1.098
144.	.606	.599	.593	.587	.581	199.	1.157	1.145	1.132	1.120	1.109
145.	.614	.608	.601	.595	.589	200.	1.169	1.156	1.144	1.132	1.120
146.	.623	.616	.610	.603	.597	201.	1.180	1.167	1.155	1.143	1.131
147.	.631	.625	.618	.611	.605	202.	1.192	1.179	1.167	1.154	1.142
148.	.640	.633	.626	.620	.613	203.	1.204	1.191	1.178	1.166	1.154
149.	.649	.642	.635	.628	.622	204	1.216	1.203	1.191	1.177	1.165
150.	.657	.650	.643	.636	.630	205.	1.228	1.215	1.202	1.189	1.176
151.	.666	.659	.652	.645	.638	206.	1.240	1.227	1.214	1.201	1.188
152.	.675	.668	.661	.654	.647	207.	1.252	1.239	1.225	1.212	1.200
153.	.684	.677	.670	.662	.655	208.	1.264	1.251	1.237	1.224	1.211
154.	.693	.686	.678	.671	.664	209.	1.276	1.263	1.249	1.236	1.223
155.	.702	.695	.687	.680	.673	210.	1.289	1.275	1.261	1.248	1.235
156.	.711	.703	.696	.689	.681	211.	1.301	1.287	1.273	1.260	1.246
157.	.720	.712	.705	.697	.690	212.	1.313	1.299	1.285	1.272	1.258
158.	.729	.721	.714	.706	.699	213.	1.326	1.311	1.297	1.284	1.270
159.	.739	.731	.723	.715	.708	214.	1.338	1.324	1.310	1.296	1.282
160.	.748	.740	.732	.724	.717	215.	1.350	1.336	1.322	1.308	1.294
161.	.757	.749	.741	.733	.726	216.	1.363	1.349	1.334	1.320	1.306
162.	.767	.759	.750	.743	.735	217.	1.376	1.361	1.347	1.332	1.318
163.	.776	.768	.760	.752	.744	218.	1.388	1.374	1.359	1.345	1.330
164.	.786	.777	.769	.761	.753	219.	1.401	1.386	1.372	1.357	1.343
165.	.795	.787	.779	.770	.762	220.	1.414	1.399	1.384	1.369	1.355
166.	.805	.797	.788	.780	.771	221.	1.427	1.412	1.397	1.382	1.367
167.	.815	.806	.798	.789	.781	222.	1.440	1.425	1.409	1.394	1.380
168.	.825	.816	.807	.799	.790	223.	1.453	1.437	1.422	1.407	1.392
169.	.835	.826	.817	.808	.800	224.	1.466	1.450	1.435	1.420	1.405
170.	.844	.835	.826	.818	.809	225.	1.479	1.463	1.448	1.432	1.417
171.	.854	.845	.836	.827	.819	226.	1.492	1.476	1.461	1.445	1.430
172.	.864	.855	.846	.837	.828	227.	1.506	1.489	1.474	1.458	1.443
173.	.874	.865	.856	.847	.838	228.	1.519	1.503	1.487	1.471	1.455
174.	.885	.875	.866	.857	.848	229.	1.532	1.516	1.500	1.484	1.468
175.	.895	.885	.876	.866	.857	230.	1.546	1.529	1.513	1.497	1.481
176.	.905	.895	.886	.876	.867	231.	1.559	1.542	1.526	1.510	1.494
177.	.915	.906	.896	.886	.877	232.	1.573	1.556	1.539	1.523	1.507
178.	.925	.916	.906	.896	.887	233.	1.586	1.569	1.553	1.536	1.520
179.	.936	.926	.916	.907	.897	234.	1.600	1.583	1.566	1.549	1.533
180.	.947	.937	.927	.917	.907	235.	1.613	1.596	1.579	1.562	1.546
181.	.957	.947	.937	.927	.917	236.	1.627	1.610	1.593	1.576	1.559
182.	.968	.957	.947	.937	.927	237.	1.641	1.624	1.606	1.589	1.572
183.	.978	.968	.958	.948	.938	238.	1.655	1.637	1.620	1.603	1.586
184.	.989	.979	.968	.958	.948	239.	1.669	1.651	1.633	1.616	1.599
185.	1.000	.989	.979	.968	.958	240.	1.683	1.665	1.647	1.630	1.613
186.	1.011	1.000	.989	.979	.969	241.	1.697	1.679	1.661	1.643	1.626
187.	1.022	1.011	1.000	.989	.979	242.	1.711	1.693	1.675	1.657	1.639
188.	1.033	1.022	1.011	1.000	.989	243.	1.725	1.707	1.689	1.671	1.653
189.	1.044	1.033	1.022	1.011	1.000	244.	1.740	1.721	1.703	1.684	1.667

Table 28—SPECIFIC GRAVITY OF GAS BY EFFUSION METHOD

Air Time 190 to 194 Seconds. Specific Gravity of Air 1.00.

Gas Time Seconds	Air Time Seconds					Gas Time Seconds	Air Time Seconds				
	190	191	192	193	194		190	191	192	193	194
140.	.543	.537	.531	.525	.520	195.	1.053	1.042	1.031	1.021	1.010
141.	.551	.545	.539	.533	.528	196.	1.064	1.053	1.042	1.031	1.021
142.	.558	.552	.546	.540	.535	197.	1.075	1.064	1.053	1.042	1.031
143.	.567	.560	.554	.548	.543	198.	1.086	1.075	1.063	1.053	1.042
144.	.575	.568	.562	.556	.551	199.	1.097	1.086	1.074	1.063	1.052
145.	.582	.576	.570	.564	.558	200.	1.108	1.096	1.085	1.074	1.063
146.	.590	.584	.578	.572	.566	201.	1.119	1.107	1.096	1.185	1.074
147.	.598	.592	.586	.580	.574	202.	1.130	1.119	1.207	1.195	1.084
148.	.606	.600	.594	.588	.582	203.	1.141	1.130	1.218	1.206	1.095
149.	.614	.608	.602	.596	.590	204.	1.152	1.141	1.229	1.217	1.105
150.	.623	.617	.610	.604	.598	205.	1.164	1.152	1.140	1.128	1.116
151.	.632	.625	.619	.612	.606	206.	1.176	1.163	1.151	1.139	1.127
152.	.640	.633	.627	.620	.614	207.	1.188	1.175	1.163	1.150	1.138
153.	.648	.642	.635	.628	.622	208.	1.199	1.186	1.174	1.162	1.150
154.	.657	.650	.643	.637	.630	209.	1.201	1.197	1.185	1.173	1.161
155.	.666	.659	.652	.645	.638	210.	1.222	1.209	1.197	1.184	1.172
156.	.674	.667	.661	.653	.647	211.	1.233	1.220	1.208	1.195	1.183
157.	.683	.676	.669	.662	.655	212.	1.245	1.231	1.219	1.207	1.194
158.	.692	.684	.677	.670	.663	213.	1.256	1.243	1.231	1.218	1.205
159.	.700	.693	.686	.679	.672	214.	1.268	1.255	1.242	1.230	1.217
160.	.709	.702	.694	.687	.680	215.	1.280	1.267	1.254	1.241	1.228
161.	.718	.711	.703	.696	.689	216.	1.292	1.279	1.266	1.253	1.240
162.	.727	.719	.712	.705	.697	217.	1.304	1.291	1.277	1.264	1.251
163.	.736	.728	.721	.713	.706	218.	1.316	1.303	1.289	1.276	1.263
164.	.745	.737	.730	.722	.715	219.	1.329	1.315	1.301	1.288	1.274
165.	.754	.746	.739	.731	.723	220.	1.341	1.327	1.313	1.299	1.285
166.	.763	.755	.748	.740	.732	221.	1.353	1.339	1.325	1.311	1.297
167.	.773	.764	.757	.749	.741	222.	1.365	1.351	1.337	1.323	1.309
168.	.782	.774	.766	.758	.750	223.	1.378	1.363	1.349	1.335	1.321
169.	.791	.783	.775	.767	.759	224.	1.390	1.376	1.361	1.347	1.333
170.	.801	.792	.784	.776	.768	225.	1.402	1.388	1.373	1.359	1.345
171.	.810	.802	.793	.785	.777	226.	1.415	1.400	1.386	1.371	1.357
172.	.820	.811	.803	.794	.786	227.	1.427	1.413	1.398	1.383	1.369
173.	.829	.820	.812	.803	.795	228.	1.440	1.425	1.410	1.396	1.381
174.	.839	.830	.821	.813	.804	229.	1.453	1.438	1.422	1.408	1.393
175.	.848	.839	.831	.822	.814	230.	1.465	1.450	1.434	1.419	1.405
176.	.858	.849	.840	.832	.823	231.	1.478	1.463	1.447	1.432	1.418
177.	.868	.859	.850	.841	.832	232.	1.491	1.475	1.460	1.445	1.430
178.	.878	.869	.859	.851	.842	233.	1.504	1.488	1.473	1.458	1.442
179.	.888	.878	.869	.860	.851	234.	1.517	1.501	1.485	1.470	1.454
180.	.898	.888	.879	.870	.861	235.	1.530	1.514	1.498	1.482	1.466
181.	.908	.898	.889	.880	.870	236.	1.543	1.527	1.511	1.495	1.479
182.	.918	.908	.898	.890	.880	237.	1.556	1.540	1.524	1.508	1.492
183.	.928	.918	.908	.899	.890	238.	1.569	1.553	1.536	1.521	1.505
184.	.938	.928	.918	.909	.900	239.	1.582	1.566	1.549	1.534	1.518
185.	.948	.938	.928	.919	.909	240.	1.596	1.579	1.562	1.546	1.530
186.	.958	.948	.938	.929	.919	241.	1.609	1.592	1.575	1.559	1.543
187.	.969	.959	.949	.939	.929	242.	1.622	1.605	1.588	1.572	1.556
188.	.979	.969	.959	.949	.939	243.	1.636	1.619	1.602	1.585	1.569
189.	.990	.979	.969	.959	.949	244.	1.649	1.632	1.615	1.598	1.582
190.	1.000	.990	.979	.969	.959	245.	1.663	1.645	1.628	1.611	1.594
191.	1.010	1.000	.990	.980	.969	246.	1.676	1.659	1.642	1.625	1.608
192.	1.021	1.010	1.000	.990	.979	247.	1.690	1.672	1.655	1.638	1.621
193.	1.032	1.021	1.010	1.000	.990	248.	1.704	1.686	1.668	1.651	1.634
194.	1.043	1.032	1.021	1.010	1.000	249.	1.717	1.700	1.682	1.665	1.647

Table 29—SPECIFIC GRAVITY OF GAS BY [illegible]FFUSION METHOD

Air Time [illegible]95 to 199 Sec[illegible]s. Specific Gravity of Air 1.00.

[illegible] Time Seconds	Air Tim[illegible]onds					Gas Time Seconds	Air Time Seconds				
	195	196	[illegible]	198	199		195	196	197	198	199
145.	.553	.547	[illegible]	.536	.531	200.	1.052	1.041	1.031	1.020	1.010
146.	.560	[illegible]	[illegible]	.543	.538	201.	1.062	1.051	1.041	1.030	1.020
147.	.568	[illegible]	[illegible]	.550	.545	202.	1.072	1.061	1.051	1.040	1.030
148.	.576	[illegible]	[illegible]	558	.553	203.	1.083	1.072	1.061	1.050	1.040
149.	.584	[illegible]	[illegible]	66	.560	204.	1.094	1.083	1.072	1.061	1.050
150.	.592	[illegible]	[illegible]	574	.568	205.	1.105	1.094	1.083	1.072	1.061
151.	.600	[illegible]	[illegible]	582	.576	206.	1.116	1.104	1.093	1.082	1.071
152.	.608	[illegible]	[illegible]	589	.583	207.	1.127	1.115	1.104	1.092	1.081
153.	.616	[illegible]	[illegible]	597	.591	208.	1.138	1.126	1.115	1.103	1.092
154.	.624	[illegible]	[illegible]	05	.599	209.	1.149	1.137	1.126	1.114	1.103
155.	.632	[illegible]	[illegible]	13	.607	210.	1.160	1.148	1.137	1.125	1.114
156.	.640	[illegible]	[illegible]	21	.615	211.	1.171	1.158	1.147	1.135	1.124
157.	.648	[illegible]	[illegible]	629	.622	212.	1.182	1.169	1.157	1.146	1.135
158.	.657	[illegible]	.643	.637	.630	213.	1.193	1.180	1.168	1.157	1.146
159.	.665	.658	.651	.645	.638	214.	1.204	1.191	1.179	1.168	1.157
160.	.673	.666	.660	.653	.646	215.	1.215	1.202	1.190	1.179	1.168
161.	.682	.675	.668	.661	.655	216.	1.226	1.213	1.201	1.190	1.178
162.	.690	.683	.676	.669	.663	217.	1.237	1.224	1.212	1.201	1.189
163.	.699	.692	.685	.678	.671	218.	1.249	1.236	1.223	1.212	1.200
164.	.707	.700	.693	.686	.679	219.	1.261	1.248	1.235	1.223	1.211
165.	.716	.709	.702	.694	.687	220.	1.273	1.260	1.247	1.234	1.222
166.	.725	.717	.710	.703	.696	221.	1.284	1.271	1.258	1.245	1.233
167.	.733	.726	.719	.711	.704	222.	1.295	1.282	1.269	1.256	1.244
168.	.742	.735	.727	.720	.713	223.	1.307	1.293	1.280	1.267	1.255
169.	.751	.743	.736	.729	.721	224.	1.319	1.305	1.292	1.279	1.266
170.	.760	.752	.745	.737	.730	225.	1.331	1.317	1.304	1.291	1.278
171.	.769	.761	.753	.746	.738	226.	1.343	1.329	1.315	1.302	1.289
172.	.778	.770	.762	.755	.747	227.	1.355	1.341	1.327	1.313	1.300
173.	.787	.779	.771	.763	.756	228.	1.367	1.353	1.339	1.325	1.312
174.	.796	.788	.780	.772	.765	229.	1.379	1.365	1.351	1.337	1.324
175.	.805	.797	.789	.781	.773	230.	1.391	1.377	1.363	1.349	1.336
176.	.815	.806	.798	.790	.782	231.	1.403	1.389	1.375	1.360	1.347
177.	.824	.816	.807	.799	.791	232.	1.415	1.401	1.387	1.372	1.358
178.	.833	.825	.816	.808	.800	233.	1.427	1.413	1.399	1.384	1.370
179.	.843	.834	.826	.817	.809	234.	1.439	1.425	1.411	1.396	1.382
180.	.852	.843	.835	.826	.818	235.	1.452	1.437	1.423	1.408	1.394
181.	.862	.853	.844	.836	.828	236.	1.464	1.449	1.435	1.420	1.406
182.	.871	.862	.854	.845	.836	237.	1.476	1.461	1.447	1.432	1.418
183.	.881	.872	.863	.854	.846	238.	1.489	1.473	1.459	1.444	1.430
184.	.890	.881	.872	.864	.855	239.	1.502	1.486	1.471	1.457	1.442
185.	.900	.891	.882	.873	.864	240.	1.515	1.499	1.484	1.470	1.455
186.	.910	.901	.891	.882	.874	241.	1.527	1.511	1.496	1.482	1.467
187.	.920	.910	.901	.892	.883	242.	1.540	1.524	1.508	1.494	1.479
188.	.929	.920	.911	.902	.893	243.	1.553	1.537	1.521	1.506	1.491
189.	.939	.930	.920	.911	.902	244.	1.566	1.550	1.534	1.518	1.503
190.	.949	.940	.930	.921	.912	245.	1.579	1.563	1.547	1.531	1.516
191.	.959	.950	.940	.931	.921	246.	1.592	1.575	1.559	1.543	1.528
192.	.969	.960	.950	.940	.931	247.	1.605	1.588	1.572	1.555	1.540
193.	.980	.970	.960	.950	.941	248.	1.618	1.601	1.585	1.568	1.552
194.	.990	.980	.970	.960	.950	249.	1.631	1.614	1.598	1.581	1.565
195.	1.000	.990	.980	.970	.960	250.	1.644	1.627	1.611	1.594	1.578
196.	1.010	1.000	.990	.980	.970	251.	1.657	1.640	1.623	1.606	1.590
197.	1.021	1.010	1.000	.990	.980	252.	1.670	1.653	1.636	1.619	1.603
198.	1.031	1.021	1.010	1.000	.990	253.	1.683	1.666	1.649	1.632	1.616
199.	1.041	1.031	1.020	1.010	1.000	254.	1.696	1.679	1.662	1.645	1.629

Heating Value and Specific Gravity—When it is impossible to obtain a calorimetric determination of the heating value of the particular gas, the next best procedure is to compute it from a chemical analysis of the gas, using the values shown in the following table for the heating value of the constituent gases.

Multiply the percentage of each gas present by its corresponding heating value per cubic foot and add the products.

The specific gravity is obtained in the same manner from the specific gravities and proportions of the constituent gases shown by the analysis.

Such computed results are necessarily subject to whatever errors there may be in the analysis of the gas, and unless this has been done with great care and precision, a wide discrepancy may exist between the calculated and the actual values. The following B. t. u. values are gross or high values, and are based on one cubic foot of gas at 60 deg. fahr. and four ounce pressure, or 14.65 pounds per square inch absolute.

Table 30

Kind of Gas	Symbol	Gross Heating Value B. t. u. per Cu. Ft.	Specific Gravity (Air—1)
Methane	CH_4	1003	0.5529
Ethane	C_2H_6	1754	1.0368
Ethylene	C_2H_4	1578	0.9676
Carbon monoxide	CO	322	0.9671
Hydrogen	H_2	324	0.0692
Hydrogen sulphide	H_2S	668	1.1769
Nitrogen	N_2	....	0.9701
Carbon dioxide	CO_2	....	1.5195
Helium	He	....	0.1382
Oxygen	O_2	....	1.1052

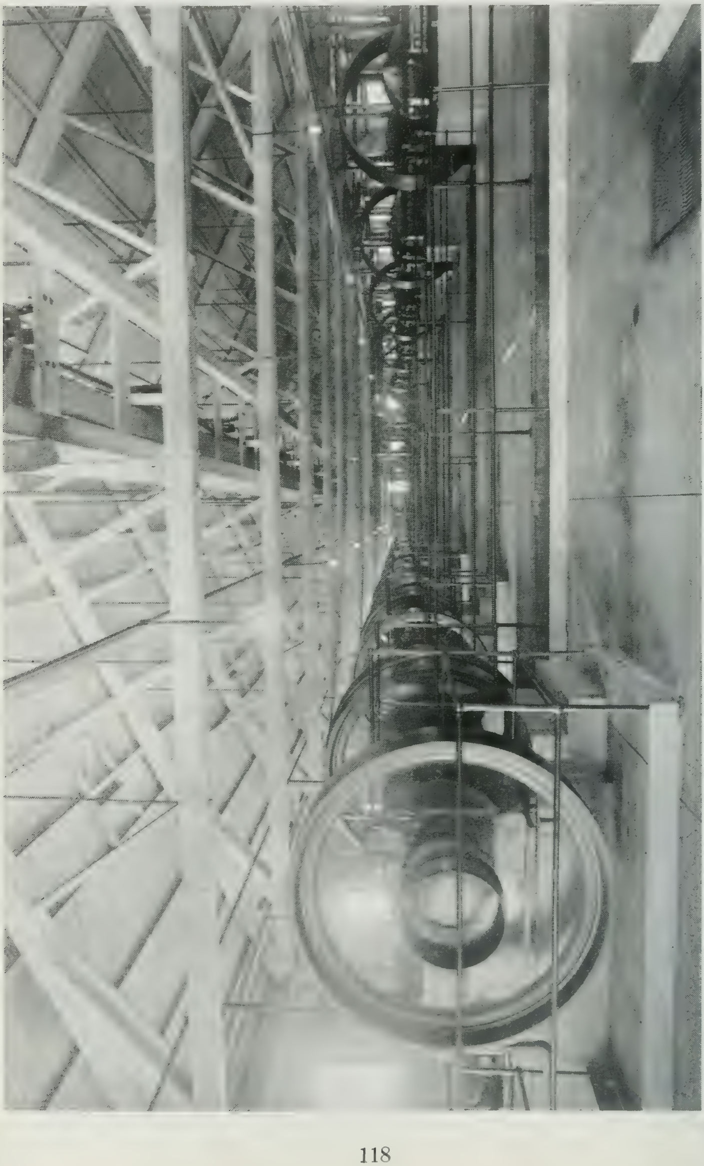


Fig. 21—INTERIOR VIEW OF BELT DRIVEN COMPRESSOR GASOLINE PLANT

PART SIX

Capacity of Casinghead Gas Wells

TESTING WELLS FOR OPEN FLOW—ORIFICE WELL TESTER CAPACITIES

Testing Wells for Open Flow—On account of the small size of most casinghead gas wells, the old method of testing the flow by using a Pitot Tube is not practical. The orifice well tester for this character of work is considered very accurate and reliable.

To use the orifice well tester the specific gravity of the gas must be taken. This is fully described in part 5.

To test a well, close all openings but one or if the well is shut in at the casinghead, blow off the well before inserting the orifice well tester. Allow the well to blow into the atmosphere until there is no appreciable decrease in the

Fig. 22—ORIFICE WELL TESTER

volume of the gas flowing from it. Screw in the orifice well tester, which carries a two inch thread, and allow the gas to flow into the atmosphere through the proper size of orifice.

Connect a syphon gauge to the nipple on the side of the orifice well tester, using a short piece of common three eighth inch rubber hose. The syphon gauge should be filled with water up to the zero mark on the scale. If the well appears

to be large use a larger sized orifice. To correctly determine the proper size of orifice it is necessary to read the gauge and note the height of the water in the glass. Read both sides of the scale and add them together. In other words, measure the difference between the two water levels which is the true pressure in inches of water. By referring to tables that accompany each instrument, or as found on pages 122-130, the flow of a well for a twenty four hour period will be found under the proper gravity and opposite the pressure.

The specific gravity bottle can be used to take the water pressure of the gas flowing through the orifice in place of the syphon gauge. Read the difference between the two levels of the water.

Use as large an orifice as possible so as not to permit the gas to create a back pressure in the well. To form a back pressure in the well will decrease the flow of the gas. A pressure between two and four inches is the most desirable.

If the wells have been flowing open for several hours or more, the pressure reading will gradually increase and remain constant after 10 or 15 minutes depending upon depth of the well. However, if the well is on a power or fuel line, after removing the casinghead plug and attaching the orifice well tester, the pressure will build up suddenly then gradually decrease more or less rapidly for 15 or 20 minutes, and afterwards very slowly. This rate of decline will be approximately the same for wells of same depth and can be determined by taking the reading on one of the larger capacity wells every five minutes for one half hour, then every 15 minutes for an hour, and finally at the end of ten or twelve hours. This can be accomplished without any loss of time by attaching the well tester for the test in the evening, taking initial readings, and leaving it remain there all night, with the gauge attached to the tester. In this manner a correc-

tion factor can be determined, to be applied to readings obtained for short periods of time at other wells and thus decrease the time required at each well. For instance, it was found in one field that the flow as determined by taking a reading at the end of a 15 minutes period was 25 per cent in excess of the result obtained after the tester has been attached for twelve hours. In this manner we were able to reduce the time required for each test to 15 minutes and apply the percentage correction factor to obtain a true open flow of each well. The correction factor of course being applied to the volume as determined from the reading at the end of the 15 minute period. The percentage factor obtained in this manner will not apply to all fields nor to all wells in the same field located over a large area.

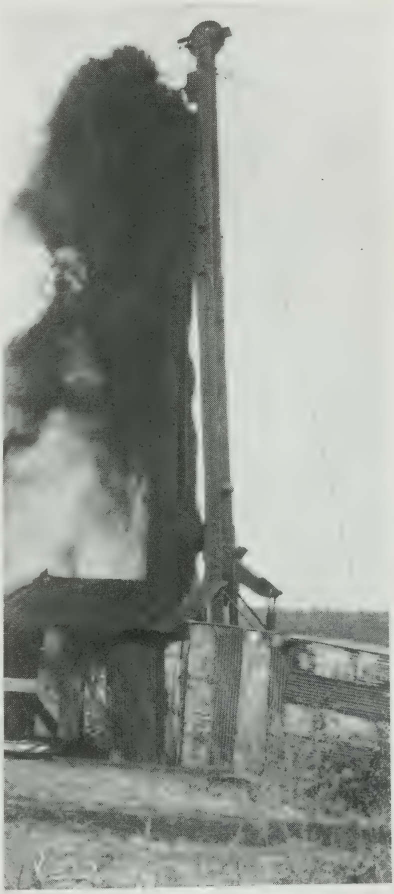


Fig. 23

Table 31—ORIFICE WELL TESTER CAPACITIES

Capacities expressed in Cubic Feet per 24 hours. Temp. 60 deg. fahr. Atmospheric Pressure 14.4.

Diameter of Orifice $\frac{1}{16}$ inch.

Press. Ins. of Water	Specific Gravity .60	.65	.70	.75	.80	.90	1.00	Press. Ins. of Water	Specific Gravity 1.10	1.20	1.30	1.40	1.50	1.60	1.70
0.5	94	90	87	84	82	77	73	0.5	69	67	64	62	60	58	56
0.6	103	99	96	92	89	84	80	0.6	76	73	70	68	65	63	61
0.7	112	108	104	100	97	92	87	0.7	83	79	76	73	71	69	67
0.8	121	117	112	108	105	99	94	0.8	90	86	82	79	77	74	72
0.9	130	125	121	117	113	106	101	0.9	96	92	89	85	82	80	77
1.0	139	134	129	125	121	114	108	1.0	103	99	95	91	88	85	83
1.2	156	150	145	140	135	128	121	1.2	115	110	106	102	99	96	93
1.4	169	162	157	151	146	138	131	1.4	125	120	115	111	107	104	100
1.6	181	174	167	162	157	148	140	1.6	133	128	123	118	114	111	107
1.8	192	185	178	172	167	157	149	1.8	142	136	130	126	122	118	114
2.0	204	196	189	182	177	166	158	2.0	151	144	139	134	129	125	121
2.2	212	203	196	189	183	173	164	2.2	156	150	144	139	134	130	126
2.4	221	212	204	197	191	180	171	2.4	163	156	150	145	140	135	131
2.6	230	221	213	206	199	188	178	2.6	170	162	156	150	145	141	137
2.8	239	229	221	214	207	195	185	2.8	176	169	162	156	151	146	142
3.0	248	238	229	222	215	202	192	3.0	183	175	168	162	157	152	147
3.2	257	247	238	236	222	210	199	3.2	190	182	174	168	162	157	153
3.4	266	256	246	238	230	217	206	3.4	196	188	181	174	168	163	158
3.6	274	263	253	245	237	223	212	3.6	202	194	186	179	173	168	163
3.8	283	272	262	253	245	231	219	3.8	209	200	192	185	179	173	168
4.0	290	279	269	260	252	237	225	4.0	211	205	197	190	184	178	173
4.5	308	296	286	276	267	252	239	4.5	228	218	210	202	195	189	183
5.0	325	313	301	291	282	266	252	5.0	240	230	221	213	206	199	193
5.5	342	329	317	306	296	279	265	5.5	253	242	232	224	216	209	203
6.0	358	344	331	320	310	292	277	6.0	264	253	243	234	226	219	212

Table 32—ORIFICE WELL TESTER CAPACITIES

Capacities expressed in Cubic Feet per 24 hours. Temp. 60 deg. fahr. Atmospheric Pressure 14.4.

Diameter of Orifice 1/8 inch.

Press. Ins. of Water	Specific Gravity							Press. Ins. of Water	Specific Gravity						
	.60	.65	.70	.75	.80	.90	1.00		1.10	1.20	1.30	1.40	1.50	1.60	1.70
0.5	465	446	430	416	402	379	360	0.5	343	329	316	304	294	285	276
0.6	507	487	470	454	439	414	393	0.6	375	359	344	332	321	311	301
0.7	549	527	508	491	475	448	425	0.7	405	388	372	359	347	336	326
0.8	587	564	544	525	509	480	455	0.8	434	415	399	385	372	360	349
0.9	620	595	574	554	537	506	480	0.9	458	438	421	406	392	379	368
1.0	650	625	602	582	563	531	504	1.0	481	460	442	426	411	398	387
1.2	713	685	660	637	617	582	552	1.2	526	504	484	467	451	436	423
1.4	775	744	717	693	671	632	600	1.4	572	548	526	507	490	474	460
1.6	831	799	770	744	720	679	644	1.6	614	588	564	544	526	509	494
1.8	886	851	820	792	767	723	686	1.8	654	626	601	580	560	542	526
2.0	938	902	869	839	813	766	727	2.0	693	664	638	614	593	575	558
2.2	989	950	916	885	856	807	766	2.2	730	699	671	647	625	606	588
2.4	1039	998	962	930	900	849	805	2.4	767	735	706	680	657	636	617
2.6	1084	1042	1004	970	939	885	840	2.6	801	767	736	710	686	664	644
2.8	1123	1079	1040	1005	973	917	870	2.8	829	794	762	735	710	688	667
3.0	1162	1116	1076	1039	1006	949	900	3.0	858	822	789	761	735	711	690
3.2	1201	1153	1112	1074	1040	980	930	3.2	887	849	815	786	759	735	713
3.4	1239	1191	1147	1109	1073	1012	960	3.4	915	876	841	811	784	759	736
3.6	1278	1228	1183	1143	1107	1044	990	3.6	944	904	868	837	808	783	759
3.8	1317	1265	1219	1178	1140	1075	1020	3.8	972	931	894	862	833	806	782
4.0	1356	1302	1255	1212	1174	1107	1050	4.0	1001	958	921	887	857	830	805
4.5	1441	1384	1334	1289	1248	1176	1116	4.5	1064	1019	979	943	911	882	856
5.0	1523	1464	1410	1363	1319	1244	1180	5.0	1125	1077	1035	997	963	933	905
5.5	1607	1544	1488	1438	1392	1312	1245	5.5	1187	1136	1092	1052	1016	984	955
6.0	1678	1612	1554	1500	1453	1370	1300	6.0	1239	1187	1140	1099	1061	1028	997

Table 33—ORIFICE WELL TESTER CAPACITIES

Capacities expressed in Cubic Feet per 24 hours. Temp. 60 deg. fahr. Atmospheric Pressure 14.4.

Diameter of Orifice ¼ inch.

Press. Ins. of Water	Specific Gravity							Press. Ins. of Water	Specific Gravity						
	.60	.65	.70	.75	.80	.90	1.00		1.10	1.20	1.30	1.40	1.50	1.60	1.70
0.5	1181	1135	1094	1056	1023	965	915	0.5	872	835	802	773	747	723	702
0.6	1260	1215	1171	1132	1096	1033	980	0.6	934	895	859	828	800	775	752
0.7	1350	1296	1249	1207	1168	1102	1045	0.7	996	954	916	883	853	826	802
0.8	1430	1371	1321	1276	1235	1165	1105	0.8	1054	1009	968	934	902	874	848
0.9	1500	1445	1392	1345	1302	1228	1165	0.9	1111	1064	1021	985	951	921	894
1.0	1575	1513	1458	1409	1364	1286	1220	1.0	1163	1114	1070	1031	996	964	936
1.2	1720	1650	1590	1536	1487	1402	1330	1.2	1268	1214	1166	1124	1086	1051	1020
1.4	1850	1786	1721	1663	1610	1518	1440	1.4	1373	1315	1262	1217	1176	1138	1104
1.6	2001	1922	1853	1790	1733	1634	1550	1.6	1478	1415	1358	1310	1266	1225	1189
1.8	2130	2046	1972	1905	1845	1739	1650	1.8	1573	1506	1446	1395	1347	1304	1266
2.0	2259	2170	2092	2020	1965	1845	1750	2.0	1668	1597	1535	1479	1428	1383	1342
2.2	2388	2295	2211	2136	2068	1950	1850	2.2	1764	1689	1621	1564	1511	1463	1419
2.4	2517	2419	2331	2252	2180	2055	1950	2.4	1859	1780	1709	1648	1592	1542	1496
2.6	2634	2530	2438	2356	2281	2150	2040	2.6	1945	1862	1788	1724	1666	1613	1565
2.8	2730	2623	2528	2442	2365	2229	2115	2.8	2016	1931	1854	1788	1727	1672	1622
3.0	2827	2716	2617	2529	2448	2308	2190	3.0	2088	2000	1921	1851	1788	1731	1680
3.2	2918	2803	2701	2610	2527	2382	2260	3.2	2155	2063	1981	1910	1845	1787	1733
3.4	3008	2890	2785	2690	2605	2456	2330	3.4	2221	2127	2042	1969	1902	1842	1787
3.6	3098	2977	2868	2771	2683	2530	2400	3.6	2288	2191	2103	2028	1960	1897	1841
3.8	3182	3057	2946	2846	2756	2598	2465	3.8	2350	2250	2160	2083	2013	1949	1891
4.0	3266	3138	3024	2921	2828	2666	2530	4.0	2412	2309	2219	2138	2065	2000	1940
4.5	3474	3336	3215	3106	3007	2835	2690	4.5	2565	2455	2359	2273	2196	2126	2063
5.0	3640	3498	3370	3256	3153	2972	2820	5.0	2688	2574	2473	2383	2302	2229	2163
5.5	3834	3684	3550	3429	3320	3130	2970	5.5	2831	2711	2605	2510	2425	2348	2278
6.0	4002	3845	3705	3580	3466	3268	3100	6.0	2955	2830	2718	2620	2531	2450	2377

Table 34—ORIFICE WELL TESTER CAPACITIES

Capacities expressed in Cubic Feet per 24 hours. Temp. 60 deg. fahr. Atmospheric Pressure 14.4.

Diameter of Orifice 3/8 inch.

Press. Ins. of Water	Specific Gravity							Press. Ins. of Water	Specific Gravity						
	.60	.65	.70	.75	.80	.90	1.00		1.10	1.20	1.30	1.40	1.50	1.60	1.70
0.5	2270	2180	2100	2030	1970	1850	1760	0.5	1680	1610	1540	1490	1440	1390	1350
0.6	2560	2460	2370	2290	2210	2090	1980	0.6	1890	1810	1730	1670	1620	1560	1520
0.7	2820	2710	2610	2520	2440	2300	2185	0.7	2080	1990	1910	1850	1780	1730	1680
0.8	3060	2940	2830	2740	2650	2500	2370	0.8	2260	2160	2080	2000	1930	1870	1820
0.9	3270	3140	3020	2920	2830	2670	2530	0.9	2410	2310	2220	2140	2070	2000	1940
1.0	3460	3320	3200	3090	3000	2820	2680	1.0	2550	2450	2350	2260	2190	2120	2050
1.2	3820	3570	3540	3420	3310	3120	2960	1.2	2820	2700	2590	2500	2420	2340	2270
1.4	4130	3970	3820	3690	3580	3370	3200	1.4	3050	2920	2800	2700	2610	2530	2450
1.6	4390	4220	4060	3920	3800	3580	3400	1.6	3240	3100	2980	2870	2780	2690	2610
1.8	4610	4430	4270	4120	3990	3760	3570	1.8	3400	3260	3130	3020	2910	2820	2740
2.0	4830	4640	4470	4320	4180	3940	3740	2.0	3560	3410	3280	3160	3050	2960	2870
2.2	5060	4860	4680	4530	4380	4130	3920	2.2	3740	3580	3430	3310	3200	3100	3010
2.4	5290	5080	4900	4730	4580	4320	4100	2.4	3910	3740	3590	3460	3350	3240	3140
2.6	5470	5250	5060	4890	4730	4460	4235	2.6	4040	3870	3710	3580	3460	3350	3250
2.8	5620	5400	5200	5030	4870	4590	4355	2.8	4150	3970	3820	3680	3550	3440	3340
3.0	5770	5550	5350	5170	5000	4720	4474	3.0	4260	4080	3920	3780	3650	3540	3430
3.2	5980	5750	5540	5350	5180	4880	4635	3.2	4420	4230	4060	3920	3780	3660	3550
3.4	6190	5950	5730	5540	5360	5050	4795	3.4	4570	4380	4200	4050	3910	3790	3680
3.6	6360	6110	5890	5690	5510	5190	4925	3.6	4690	4500	4320	4160	4020	3890	3780
3.8	6510	6250	6020	5820	5630	5310	5040	3.8	4800	4600	4420	4260	4110	3980	3860
4.0	6650	6390	6160	5950	5760	5430	5152	4.0	4910	4700	4520	4350	4210	4070	3950
4.5	7210	6930	6680	6450	6240	5890	5585	4.5	5330	5100	4900	4720	4560	4410	4280
5.0	7680	7380	7110	6870	6650	6270	5946	5.0	5670	5430	5210	5020	4850	4700	4560
5.5	8100	7790	7500	7250	7020	6620	6278	5.5	5980	5730	5510	5310	5130	4960	4810
6.0	8290	7970	7680	7420	7180	6770	6423	6.0	6120	5860	5630	5430	5240	5080	4930

Table 35—ORIFICE WELL TESTER CAPACITIES

Capacities expressed in Cubic Feet per 24 hours. Temp. 60 deg. fahr. Atmospheric Pressure 14.4.

Diameter of Orifice ½ inch.

Press. Ins. of Water	Specific Gravity							Press. Ins. of Water	Specific Gravity						
	.60	.65	.70	.75	.80	.90	1.00		1.10	1.20	1.30	1.40	1.50	1.60	1.70
0.5	4490	4320	4160	4020	3890	3670	3480	0.5	3320	3180	3050	2940	2840	2750	2670
0.6	4890	4700	4530	4380	4240	4000	3790	0.6	3610	3460	3320	3200	3090	3000	2910
0.7	5270	5060	4880	4710	4560	4300	4080	0.7	3890	3720	3570	3450	3330	3220	3130
0.8	5600	5380	5190	5010	4850	4570	4340	0.8	4140	3960	3800	3670	3540	3430	3330
0.9	5940	5700	5500	5310	5140	4850	4600	0.9	4380	4200	4030	3890	3750	3640	3530
1.0	6260	6010	5790	5600	5440	5110	4850	1.0	4620	4420	4250	4100	3960	3830	3720
1.2	6910	6630	6390	6180	5980	5640	5350	1.2	5100	4880	4690	4520	4370	4230	4100
1.4	7550	7250	6990	6750	6540	6170	5850	1.4	5580	5340	5130	4940	4780	4620	4490
1.6	8160	7840	7550	7300	7060	6660	6320	1.6	6020	5770	5540	5340	5160	5000	4850
1.8	8650	8310	8010	7740	7490	7060	6700	1.8	6390	6120	5870	5660	5470	5300	5140
2.0	9140	8780	8460	8170	7910	7460	7080	2.0	6750	6460	6210	5980	5780	5600	5430
2.2	9590	9210	8880	8580	8310	7830	7430	2.2	7080	6780	6510	6280	6070	5870	5700
2.4	10020	9620	9270	8960	8670	8180	7760	2.4	7400	7080	6800	6560	6340	6130	5950
2.6	10430	10020	9660	9330	9030	8520	8080	2.6	7700	7380	7080	6830	6600	6390	6200
2.8	10800	10380	10000	9660	9360	8820	8370	2.8	7980	7640	7330	7070	6830	6620	6420
3.0	11150	10720	10330	9980	9660	9110	8640	3.0	8240	7890	7580	7300	7050	6830	6630
3.2	11500	11050	10650	10290	9960	9390	8910	3.2	8490	8130	7810	7530	7270	7040	6830
3.4	11850	11380	10970	10600	10260	9680	9180	3.4	8750	8380	8040	7760	7490	7260	7040
3.6	12170	11700	11270	10890	10540	9940	9430	3.6	8990	8610	8260	7970	7700	7450	7230
3.8	12480	11990	11560	11160	10810	10190	9670	3.8	9220	8830	8470	8170	7890	7640	7420
4.0	12800	12290	11850	11440	11080	10450	9910	4.0	9450	9050	8690	8380	8090	7840	7600
4.5	13480	12950	12480	12050	11670	11000	10440	4.5	9950	9530	9160	8820	8520	8250	8010
5.0	14130	13570	13080	12640	12230	11530	10940	5.0	10430	9990	9600	9250	8930	8650	8390
5.5	14690	14110	13600	13130	12720	11990	11380	5.5	10850	10380	9980	9610	9290	8990	8720
6.0	15210	14620	14080	13610	13170	12420	11780	6.0	11230	10760	10330	9960	9620	9310	9040

Table 36—ORIFICE WELL TESTER CAPACITIES

Capacities expressed in Cubic Feet per 24 hours. Temp. 60 deg. fahr. Atmospheric Pressure 14.4.

Diameter of Orifice ¾ inch.

Press. Ins. of Water	Specific Gravity .60	.65	.70	.75	.80	.90	1.00
0.5	10560	10150	9780	9450	9150	8630	8180
0.6	11490	11040	10640	10280	9950	9380	8900
0.7	12290	11810	11380	10990	10640	10030	9520
0.8	13100	12590	12130	11720	11350	10700	10150
0.9	13890	13350	12860	12420	12030	11340	10760
1.0	14530	13960	13450	13000	12580	11860	11260
1.2	15880	15250	14700	14200	13750	12960	12300
1.4	17170	16490	15900	15360	14870	14020	13300
1.6	18240	17520	16890	16310	15800	14890	14130
1.8	19310	18550	17880	17270	16720	15770	14960
2.0	20390	19590	18870	18230	17650	16650	15790
2.2	21330	20490	19740	19070	18470	17410	16520
2.4	22270	21390	20610	19920	19280	18180	17250
2.6	23170	22260	21450	20730	20070	18920	17950
2.8	24010	23070	22230	21480	20790	19610	18600
3.0	24880	23900	23030	22250	21550	20310	19270
3.2	25740	24730	23830	23020	22290	21020	19940
3.4	26590	25550	24620	23790	23030	21710	20600
3.6	27420	26340	25390	24520	23750	22390	21240
3.8	28190	27090	26100	25220	24420	23020	21840
4.0	28970	27830	26820	25910	25090	23650	22440
4.5	30800	29590	28510	27550	26670	25150	23860
5.0	32500	31230	30090	29070	28150	26540	25180
5.5	34080	32740	31530	30480	29510	27830	26400
6.0	35630	34230	32990	31870	30860	29090	27600

Press. Ins. of Water	Specific Gravity 1.10	1.20	1.30	1.40	1.50	1.60	1.70
0.5	7800	7470	7170	6920	6680	6470	6280
0.6	8480	8120	7800	7520	7270	7040	6830
0.7	9080	8690	8340	8050	7770	7530	7300
0.8	9680	9260	8890	8580	8290	8020	7780
0.9	10260	9820	9430	9090	8780	8510	8250
1.0	10730	10280	9870	9510	9190	8900	8630
1.2	11730	11230	10780	10390	10040	9720	9430
1.4	12680	12140	11660	11240	10860	10510	10200
1.6	13470	12900	12380	11940	11540	11170	10840
1.8	14260	13660	13110	12640	12210	11830	11470
2.0	15060	14420	13850	13350	12890	12480	12110
2.2	15750	15080	14480	13960	13490	13060	12670
2.4	16450	15750	15120	14580	14080	13640	13230
2.6	17110	16390	15730	15170	14660	14190	13770
2.8	17730	16980	16300	15720	15190	14700	14270
3.0	18380	17590	16900	16290	15730	15230	14780
3.2	19010	18200	17470	16850	16280	15760	15290
3.4	19640	18800	18050	17410	16820	16290	15800
3.6	20250	19390	18610	17950	17340	16790	16290
3.8	20820	19940	19140	18460	17830	17270	16750
4.0	21400	20480	19680	18960	18320	17740	17210
4.5	22750	21700	20920	20160	19480	18860	18300
5.0	24000	22980	22080	21280	20550	19900	19310
5.5	25170	24100	23150	22310	21550	20870	20250
6.0	26310	25200	24200	23330	22530	21820	21170

Table 37—ORIFICE WELL TESTER CAPACITIES

Capacities expressed in Cubic Feet per **24** hours. Temp. **60** deg. fahr. Atmospheric Pressure **14.4**.

Diameter of Orifice 1 inch.

Press. Ins. of Water	Specific Gravity							Press. Ins. of Water	Specific Gravity						
	.60	.65	.70	.75	.80	.90	1.00		1.10	1.20	1.30	1.40	1.50	1.60	1.70
0.5	18650	17920	17270	16680	16150	15230	14450	0.5	13780	13190	12660	12210	11800	11420	11080
0.6	20400	19600	18880	18240	17660	16650	15800	0.6	15060	14420	13850	13350	12900	12490	12120
0.7	22080	21210	20440	19740	19120	18020	17100	0.7	16300	15610	14990	14450	13960	13520	13110
0.8	23620	22700	21870	21130	20460	19290	18300	0.8	17450	16710	16040	15470	14940	14470	14040
0.9	25040	24060	23190	22400	21690	20450	19400	0.9	18490	17710	17000	16400	15840	15340	14880
1.0	26440	25440	24500	23660	22920	21600	20520	1.0	19560	18720	18000	17320	16750	16200	15720
1.2	28920	27780	26770	25860	25040	23610	22400	1.2	21360	20450	19630	18930	18290	17710	17180
1.4	31110	29900	28800	27830	26950	25610	24100	1.4	22980	22000	21130	20370	19680	19030	18490
1.6	33310	32000	30840	29790	28840	27190	25800	1.6	24600	23550	22610	21810	21060	20400	19790
1.8	35500	34110	32870	31750	30740	28990	27500	1.8	26220	25100	24100	23240	22450	21740	21090
2.0	37510	36040	34750	33600	32520	30640	29080	2.0	27720	26540	25480	24570	23760	22990	22290
2.2	39370	37830	36450	35220	34100	32150	30500	2.2	29080	27840	26730	25780	24900	24110	23390
2.4	41180	39560	38130	36830	35660	33620	31900	2.4	30410	29120	27960	26960	26050	25220	24470
2.6	42860	41180	39680	38340	37120	35000	33200	2.6	31650	30310	29100	28060	27110	26250	25460
2.8	44670	42910	41350	39950	38680	36470	34600	2.8	32990	31590	30320	29240	28250	27350	26540
3.0	46440	44640	43000	41540	40240	37940	36000	3.0	34320	32850	31560	30400	29370	28440	27600
3.2	47770	45890	44220	42720	41370	39000	37000	3.2	35270	33780	32430	31270	30210	29250	28380
3.4	49060	47130	45420	43880	42480	40050	38000	3.4	36230	34690	33300	32120	31030	30040	29150
3.6	50350	48370	46610	45030	43600	41110	39000	3.6	37180	35600	34180	32960	31840	30830	29910
3.8	51510	49490	47690	46070	44610	42060	39900	3.8	38040	36420	34970	33720	32580	31540	30600
4.0	52630	50590	48740	47060	45600	42980	40800	4.0	38880	37220	35760	34460	33310	32230	31270
4.5	55310	53130	51200	49470	47890	45160	42840	4.5	40840	39110	37540	36210	34980	33870	32860
5.0	57880	55630	53610	51790	50160	47280	44880	5.0	42760	40940	39360	37920	36620	35470	34410
5.5	60570	58190	56080	54180	52460	49460	46920	5.5	44730	42830	41120	39660	38310	37090	35990
6.0	63140	60720	58480	56490	54720	51600	48960	6.0	46650	44680	42960	41370	39960	38680	37530

For other values for 1 inch Orifice, see page 129.

Table 38—ORIFICE WELL TESTER CAPACITIES

Capacities expressed in thousands of Cubic Feet per 24 hours. Temp. 60 deg. fahr. Atmospheric Pressure 14.4.

Diameter of Orifice 1 inch.

Press. Ins. of Water	Specific Gravity .60	.65	.70	.75	.80	.90	1.00	Press. Ins. of Water	Specific Gravity 1.10	1.20	1.30	1.40	1.50	1.60	1.70
7	68	65	63	61	59	56	53	7	50	48	46	45	43	42	40
8	73	70	68	65	63	60	57	8	54	52	50	48	46	45	43
9	78	75	72	70	67	63	60	9	57	55	53	51	49	48	46
10	82	79	76	74	71	67	64	10	61	58	56	54	52	50	49
11	87	83	80	78	75	71	67	11	64	61	59	57	55	53	52
12	91	87	84	81	79	74	70	12	67	64	62	59	57	56	54
Press. Ins. of Mercury								Press. Ins. of Mercury							
0.5	67	65	62	60	58	55	52	0.5	50	48	46	44	43	41	40
1.0	95	92	88	85	83	78	74	1.0	70	67	65	62	60	58	57
1.5	117	112	108	104	101	95	90	1.5	86	83	79	76	74	71	69
2.0	135	129	125	120	117	110	104	2.0	100	95	92	88	85	83	80
2.5	146	140	135	130	126	119	113	2.5	108	103	99	95	92	89	87
3.0	165	159	153	148	143	135	128	3.0	122	117	112	108	104	101	98
3.5	178	171	165	159	155	146	138	3.5	132	126	121	117	113	109	106
4.0	190	183	176	170	165	156	148	4.0	141	135	129	125	121	117	113
5.0	213	205	197	190	185	174	165	5.0	157	151	145	139	135	130	127
6.0	233	224	216	209	202	191	181	6.0	172	165	159	153	148	143	139
7.0	252	242	233	225	218	206	195	7.0	186	178	171	165	159	154	150
8.0	269	259	250	241	233	220	209	8.0	199	191	183	176	171	165	160
9.0	286	275	265	256	248	234	222	9.0	211	202	194	187	181	175	170
10.0	301	290	279	269	261	246	234	10.0	223	213	205	197	191	185	179
11.0	316	204	293	283	274	258	245	11.0	233	223	215	207	200	194	188
12.0	328	316	304	294	285	268	255	12.0	243	232	223	215	208	201	195

For other values for 1 inch Orifice, see page 128.

Table 39—ORIFICE WELL TESTER CAPACITIES

Capacities expressed in Cubic Feet per 24 hours. Temp. 60 deg. fahr. Atmospheric Pressure 14.4.

Diameter of Orifice 1¼ inch.

Press. Ins. of Water	Specific Gravity							Press. Ins. of Water	Specific Gravity						
	.60	.65	.70	.75	.80	.90	1.00		1.10	1.20	1.30	1.40	1.50	1.60	1.70
0.5	32780	31490	30350	29320	28390	26760	25390	0.5	24210	23180	22270	21458	20730	20070	19470
0.6	36020	34600	33350	32220	31190	29410	27900	0.6	26600	25470	24450	23580	22780	22060	21400
0.7	39000	37460	36090	34870	33760	31830	30200	0.7	28790	27570	26470	25520	24660	23880	23160
0.8	41700	40060	38600	37300	36110	34050	32300	0.8	30790	29490	28310	27300	26370	25540	24770
0.9	44150	42420	40870	39490	38230	36050	34200	0.9	32610	31220	29970	28900	27920	27040	26230
1.0	46260	44440	42830	41380	40060	37770	35830	1.0	34160	32710	31420	30280	29250	28320	27480
1.2	50350	48370	46610	45030	43600	41110	39000	1.2	37180	35600	34180	32960	31840	30830	29910
1.4	54350	52220	50320	48610	47070	44380	42100	1.4	40140	38430	36900	35580	34370	33280	32290
1.6	58090	55810	53780	51960	50310	47430	45000	1.6	42900	41080	39440	38030	36740	35580	34510
1.8	61450	59040	56890	54960	53220	50170	47600	1.8	45380	43450	41720	40230	38860	37630	36510
2.0	64840	62300	60040	58000	56160	52940	50230	2.0	47890	45850	44050	42450	41010	39710	38520
2.2	67650	64990	62630	60510	58580	55230	52400	2.2	49960	47830	45920	44290	42780	41430	40190
2.4	70490	67720	65260	63050	61040	57550	54600	2.4	52050	49840	47850	46150	44580	43170	41880
2.6	73330	70450	67890	65590	63500	59870	56800	2.6	54150	51850	49780	48010	46380	44910	43560
2.8	75650	72680	70040	67660	65510	61770	58600	2.8	55870	53490	51360	49530	47850	46330	44950
3.0	77980	74920	72200	69750	67540	63670	60410	3.0	57600	55150	52980	51050	49320	47760	46330
3.2	80560	77390	74580	72050	69760	65770	62400	3.2	59490	56960	54690	52740	50950	49330	47860
3.4	83140	79870	76970	74360	72000	67880	64400	3.4	61400	58790	56440	54430	52580	50910	49390
3.6	85720	82350	79360	76670	74230	69990	66400	3.6	63300	60620	58190	56120	54210	52490	50930
3.8	88560	85080	81990	79210	76690	72310	68600	3.8	65400	62620	60120	57980	56010	54230	52620
4.0	91400	87810	84620	81750	79150	74620	70800	4.0	67500	64630	62090	59840	57810	55970	54300
4.5	97810	93980	90560	87490	84710	79860	75770	4.5	72240	69170	66450	64040	61860	59900	58110
5.0	103260	99210	95610	92370	89430	84310	80000	5.0	76280	73030	70160	67610	65320	63240	61350
5.5	107230	103020	99280	95910	92870	87550	83060	5.5	79190	75820	72850	70200	67820	65660	63700

PART SEVEN

Gasoline Content of Gas

SPECIFIC GRAVITY AND GASOLINE CONTENT —NEWTON ABSORBER—SINGLE AND FOUR COIL ABSORBER—DYKEMA ABSORBER—CHARCOAL METHOD

Quality of Casinghead Gas—While it is possible to send samples of casinghead gas to some laboratory or chemist for analysis and gravity test, and the practice has been quite common, the results obtained are not as satisfactory as in taking the tests on the ground at the well. The opportunity of leakage of oxygen or air into the sample bottle while enroute to the laboratory is very great and the time required enroute to the chemist entails considerable delay. Heretofore, it has been the only course open to the possible investor; but with the manufacturing of a simple analyzing outfit that is portable, and with the plain instructions accompanying same, the operations in the field have become far less difficult and good reliable results are obtained.

The preliminary operations in testing casinghead gas for quality are as follows:

First—Take the specific gravity of the gas from each well under consideration and eliminate the poor wells, i. e., all wells that show a gravity of less than 0.80 when intending to extract gasoline by the compression method. Gasoline can be extracted from casinghead gas under 0.80 by the absorption method. Full instructions for use of the specific gravity apparatus will be found in Part 5.

Keep a careful record of all wells showing gas of gravity of better than 0.80 or less as the case may be.

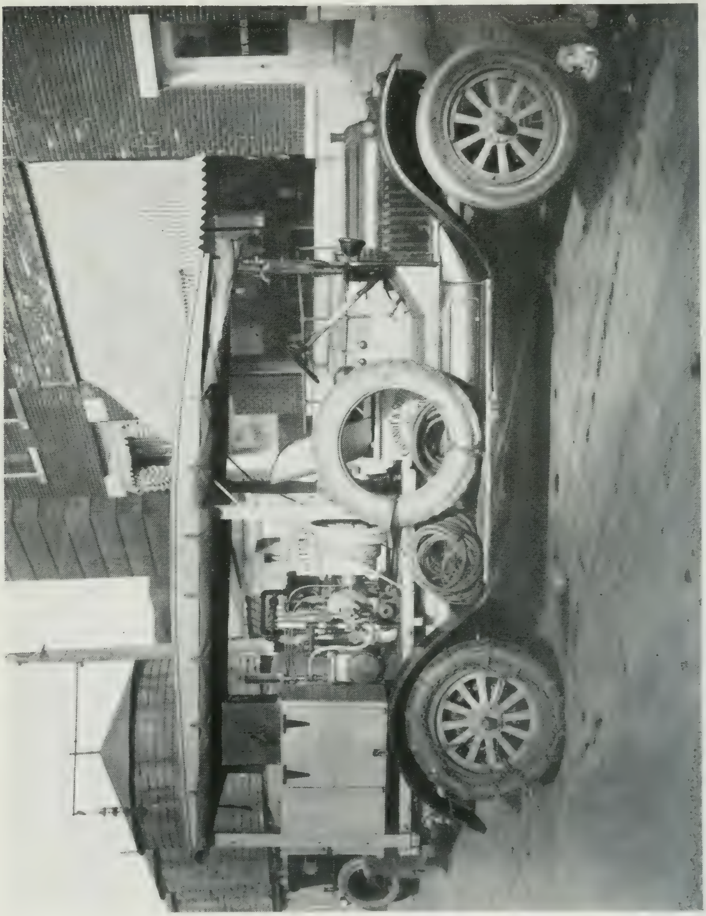


Fig. 24—HEAVY TYPE OF PORTABLE TESTING APPARATUS FOR TESTING CASINGHEAD GAS

While the gravity of the gas merely shows that it may carry gasoline or in other words the gas is dense or heavy, it must not be taken for granted that the gas carries gasoline in paying quantity for either process. The high gravity shows that the gas carries constituents other than methane but it does not show what the additional constituents are.

SECOND—Assuming that the gas ran high enough in gravity to warrant further investigation—make an analysis for gasoline content with some portable analyzing outfit as shown in following pages.

If by this analysis the gas shows enough gasoline to warrant considering, it is far more conclusive than if merely the specific gravity of the gas is known, but even this is not sufficiently conclusive to warrant the investment of a large amount of money in a plant.

There are two reasons for first testing with the specific gravity outfit, one—the gravity is necessary in obtaining the volume or capacity of the well and the other—that the poor wells can quickly be determined and eliminated from further consideration.

The two outfits—specific gravity and analyzing outfits—are easily carried from well to well without any great inconvenience.

THIRD OR FINAL STEP—That is to prove the quality of the gas in a practical experiment by use of a portable testing outfit, which is nothing more than a miniature gasoline plant installed on an automobile, receiving its power from either a small engine or by belt from one of the rear wheels when it is jacked up.

The portable testing outfit consists of a small gasoline engine, usually 1 or 2 hp., a small compressor, a 300 cu. ft. per hour gas meter, 30 or more feet of cooling coils made of small pipe immersed in a tank of water, and a small storage

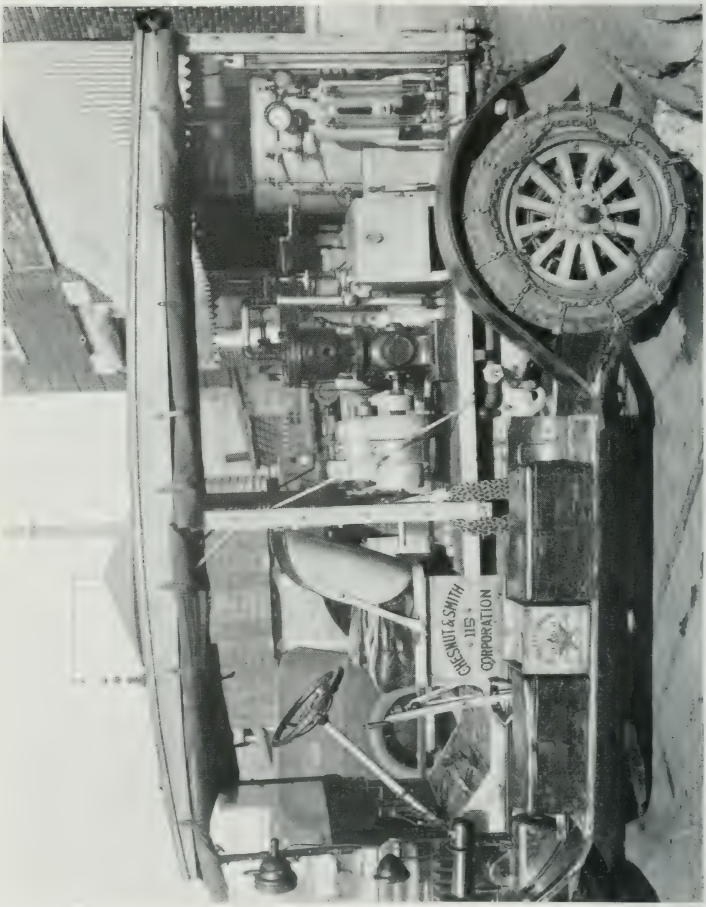


Fig. 25—SAME AS Fig. 24

tank. To the latter should be attached a relief valve which can be set to operate at the pressure desired. A trap should be installed between the compressor and the cooling coils to catch oil that is sometimes brought from the well with the gas. A glass gauge should be connected to the storage tank to indicate the amount of gasoline obtained.

In conducting test of casinghead gas, the plant should first be run long enough to expel all air from the compressor and lines. The meter and pressure gauges must be in good order. The cooling coils should dip enough to readily drain the gasoline into the storage tank. The efficiency of the cooling coils can be ascertained fairly well by measuring the temperature at different places in the water of the tank. At the point where the coils enter the water it will be hot enough to warm the water appreciably, but if the tank is large and a sufficient length of pipe for cooling purposes is installed the warming of the water is only local.

The pressure of the gas passing through the meter must be taken in order to ascertain the actual volume of gas treated. (For multiplier tables see part 10.)

It can hardly be said necessary to make a compressor test on the gas from every well in a group of wells on one lease or adjoining leases but it is essential to do so on at least one half of the wells. The specific gravity test on the gas from each well will show any variation in density of the gas and is very necessary in determining the capacity of the wells.

After the quality of the gas is fully and carefully determined then the only remaining question is as to the quantity of gas a well or group of wells will supply.

Specific Gravity Test*—"Natural gas having a specific gravity of 0.78 (air = 1) and higher is being successfully treated in compression plants. The specific gravity test is useful as an indicator, but the possibility of misleading

* W. P. Dykema in Bulletin 151, Bureau of Mines.

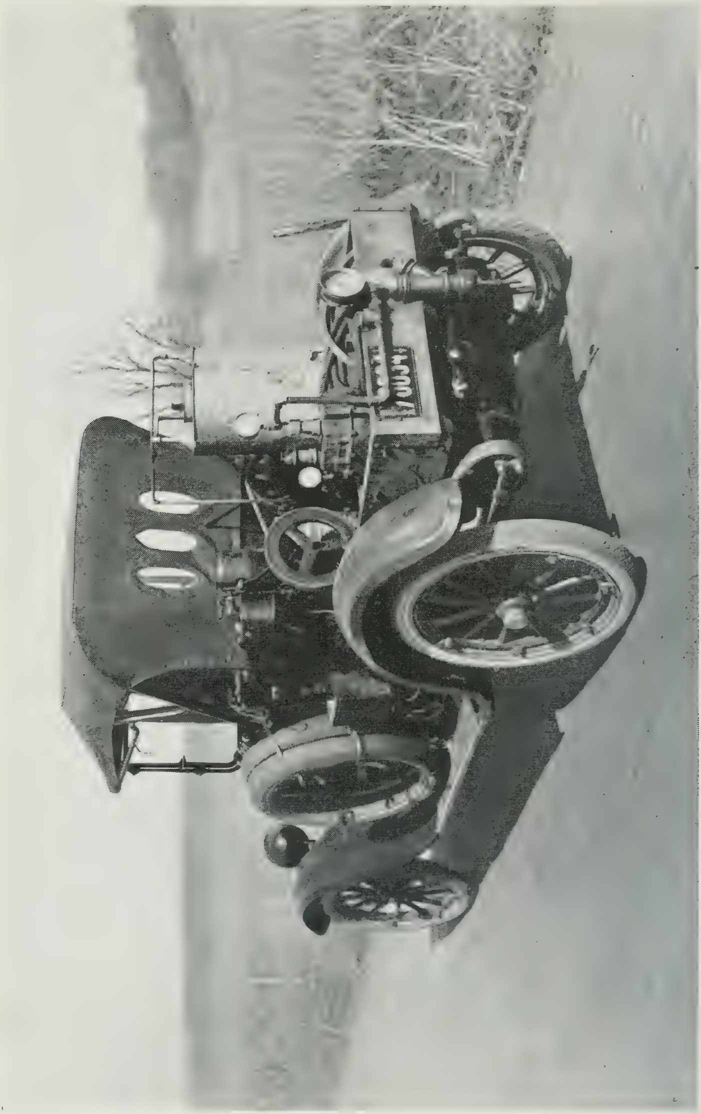


Fig. 26—PORTABLE TESTING OUTFIT FOR TESTING CASINGHEAD GAS FROM INDIVIDUAL WELLS. IN THIS OUTFIT POWER IS SUPPLIED BY A TWO HORSE POWER GAS ENGINE

variations through the presence of other gases, such as air, carbon dioxide, nitrogen and sulphur compounds, in the sample makes this test unreliable if used alone. If an analysis is made of the gas and the specific gravity of the hydrocarbon contents computed, the results are more dependable, but even then are not reliable enough to be used as a basis for final decisions regarding plant construction."

In one field where the specific gravity of gas ranged from 1.20 to 1.50 and where the results obtained by the absorption method of testing; that is, indications obtained by the percentage of gas absorbed in oil indicated a probable yield from 5½ to 7 gallons per thousand cubic feet, complete tests by absorption in oil and distillation, by absorption in charcoal and distillation, also by portable compressor indicated less than 2 gallons of marketable gasoline per thousand cubic feet. This gas was also tested by small hand compression apparatus producing a condensate equivalent to 13½ gallons per thousand cubic feet. This condensate upon exposure to air entirely weathered away. As previous tests indicated no carbon dioxide, air, nitrogen or other impurities, the specific gravity and percentage of absorption in oil was entirely due to the heavier hydrocarbon components, which were not heavy enough to form gasoline.

"It has been stated that if a specific gravity test is accompanied by an analysis to determine whether the high specific gravity is due to carbon dioxide, and air or nitrogen, or to heavy paraffin hydrocarbons, and it is shown to be due to heavy hydrocarbons, that the specific gravity test in such a case affords a fair indication of the gasoline content of the gas; however, it should be borne in mind that the high specific gravity might be due to very large quantities of the very volatile constituents of natural gas gasoline, such as Ethane (Sp. Gr. 1.038, B. P.—119.4 deg. fahr.) Propane, (Sp. Gr. 1.523, B. P.—47.4 deg. fahr.) and Butane, (Sp. Gr. 2.007, B. P. plus 32.5 deg. fahr.).

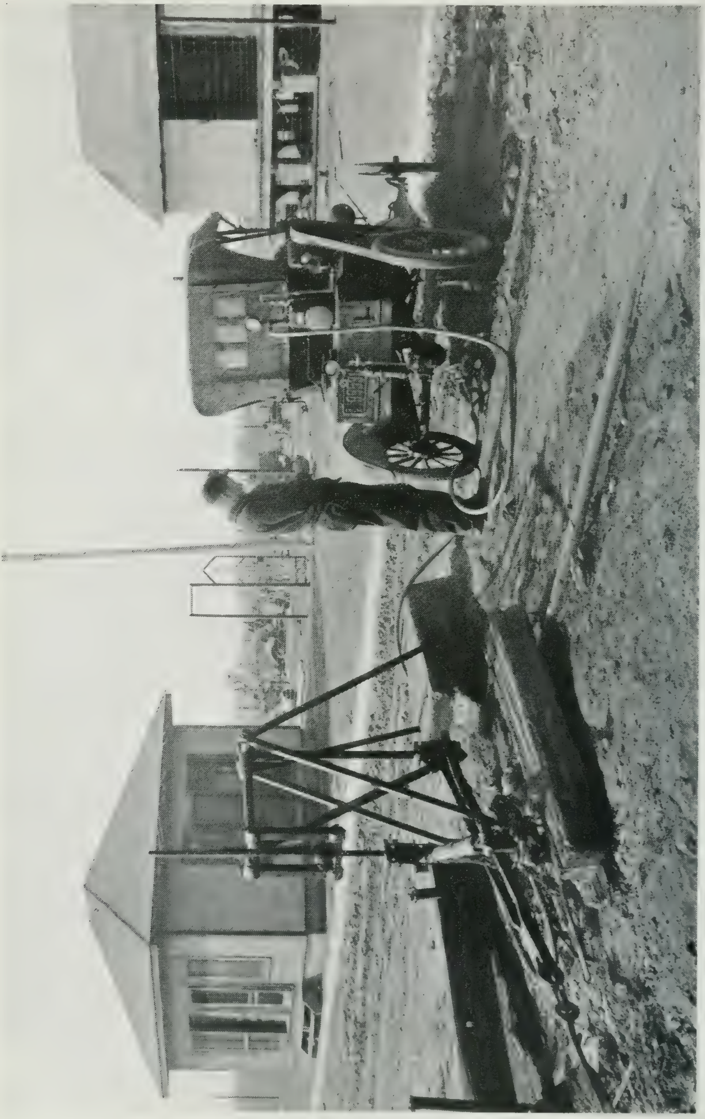


Fig. 27—TESTING GAS FROM A CASINGHEAD GAS WELL

Table 40
SPECIFIC GRAVITY AND GASOLINE CONTENT*

Specific Gravity Air=1	Gallons per M. Cu. Ft.	Remarks
0.60	.06	Yields estimated from gas density alone may be several hundred per cent in error.
0.61	.11	It is recommended that in all cases the yields should be checked by some accurate and direct method of analysis.
0.62	.16	
0.63	.21	
0.64	.26	
0.65	.32	
0.66	.39	
0.67	.45	
0.68	.50	
0.69	.58	
0.70	.64	
0.71	.70	
0.72	.77	
0.73	.83	
0.74	.90	
0.75	.96	
0.76	1.01	
0.77	1.07	
0.78	1.14	
0.79	1.20	
0.80	1.27	
0.81	1.34	
0.82	1.40	
0.83	1.46	
0.84	1.52	
0.85	1.59	
0.86	1.65	
0.87	1.71	
0.88	1.76	
0.89	1.82	
0.90	1.90	
0.95	2.21	
1.00	2.53	
1.05	2.85	
1.10	3.17	
1.15	3.49	
1.20	3.81	
1.25	4.13	
1.30	4.45	
1.35	4.77	
1.40	5.09	
1.45	5.41	
1.50	5.73	

* By G. G. Oberfell.

It is common knowledge that there are gases with high specific gravities which have low gasoline values, due to the fact that the gas contains a large percentage of the very volatile constituents of natural gas gasoline. The gasoline made from this gas is very "wild" and has to undergo very large weathering losses before the product can be marketed."*

Table 41

Specific Gravity Air=1	Yield Gal. per M.	Specific Gravity Air=1	Yield Gal. per M.
0.57	0.00	1.00	2.00
0.58	0.00	1.00	2.50
0.65	0.12	1.01	1.05
0.65	0.25	1.03	2.50
0.65	0.92	1.03	1.13
0.67	0.23	1.03	1.22
0.68	0.39	1.03	1.26
0.69	1.17	1.03	1.22
0.70	0.62	1.04	3.00
0.72	0.63	1.07	1.12
0.75	0.50	1.07	0.82
0.76	0.65	1.07	3.00
0.77	0.31	1.07	0.92
0.77	0.34	1.07	0.98
0.78	0.90	1.09	1.55
0.80	1 00	1 12	3.00
0.83	1.00	1.16	4.00
0.85	0.85	1.21	3.50
0.85	2.65	1.23	4.50
0.86	1.13	1.29	2.12
0.87	0.69	1.29	3.00
0.90	2.00	1.30	5.00
0.91	1.95	1.33	2.80
0.93	0.80	1.35	2.06
0.93	1.09	1.35	2.64
0.94	2.00	1.35	6.60
0.95	3.75	1.37	3.50
0.96	2.10	1.37	5.50
0.98	3.50	1.38	4.00
0.98	3.75	1.44	1.80
0.99	1.21	1.46	5.00
1.00	1.15	1 50	1.89

Table 41 shows the yields per thousand cubic feet corresponding to various specific gravities. These are

* G. G. Oberfell.

the results of plant experience and it is very possible that the yield obtained from other fields may be greater than the maximum or less than the minimum of the values given for various specific gravities. It shows that the specific gravity does not indicate probable yield except within very wide limits.

THE NEWTON ABSORPTION TESTER

The Newton Absorption Tester, shown in Fig. 29, is a very simple field apparatus that the layman can easily operate without the aid of a distillation outfit. It was originally designed by Mr. D. L. Newton, of Fullerton, Calif. The figures given were mainly obtained by practical tests at gasoline plants where the amount of gasoline obtained from the gas absorption process was known. This apparatus will not show the full amount of gasoline in the gas but will show the amount of gasoline that can be obtained at an efficient absorption plant of large capacity.

The apparatus consists of an absorber, 10 feet of 1/4 inch hose, a siphon gauge, a relief valve or regulator, and some mineral seal oil of 35 deg. Baume gravity. The entire outfit is carried in a metal case 24 in. by 6 in. by 6 in. (with top off) and a well can be tested within forty-five minutes.

Make connection with the gas to be tested, as shown in Fig. 29.

Allow the gas to run through the hose a few minutes.

Place absorber in a vertical position and pour mineral seal oil into the absorber until you have 125 cc., which is indicated on the glass on the side of the absorber.

Connect hose with absorber.

Eight inches of water pressure should be carried on the gas. The relief valve will assist in keeping this pressure constant.

Take the time when the gas is first turned into the absorber and allow it to run through it for thirty minutes.

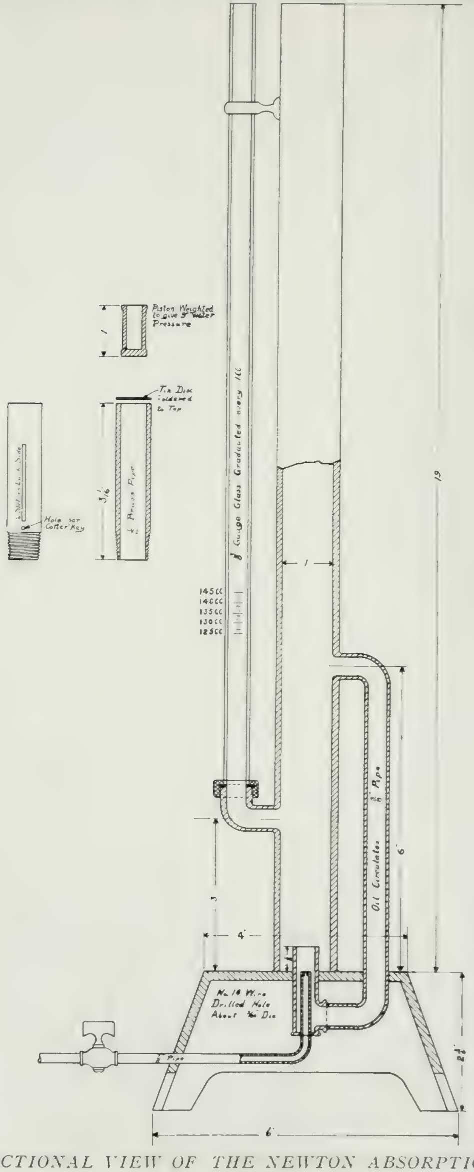


Fig. 28—SECTIONAL VIEW OF THE NEWTON ABSORPTION TESTER

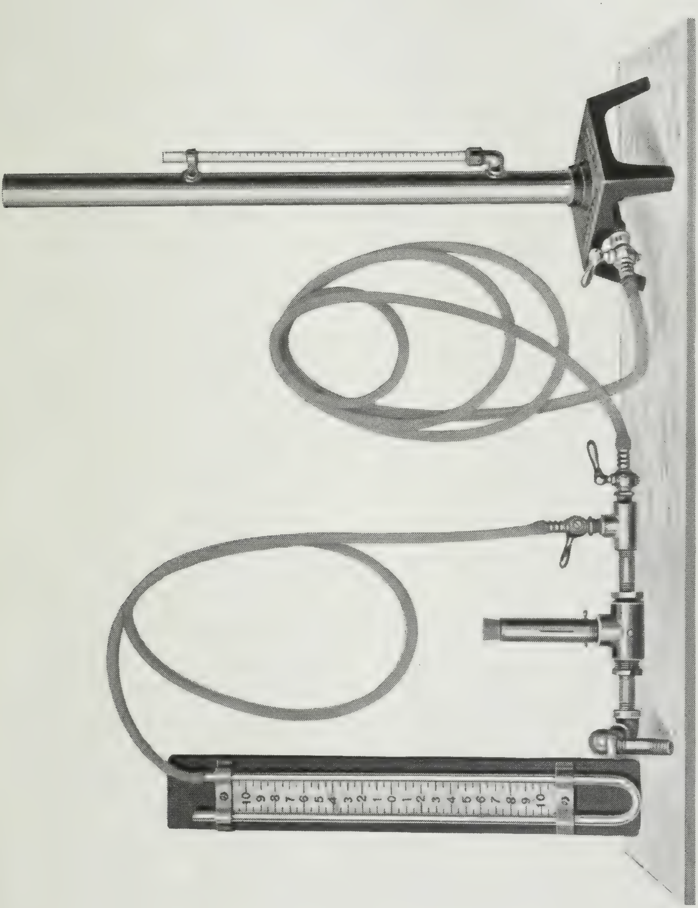


Fig. 29—THE NEWTON ABSORPTION TESTER

Note the reading of the mineral seal oil level on the glass and deduct the original level reading.

Multiply the difference or increase in cc. by $1\frac{1}{3}$ and the results will be pints per thousand cubic feet of gas.

The orifice on the end of the short nipple screwed in the center of the lower end of the absorber will pass a certain amount of gas per hour at an eight-inch water pressure. This orifice should be kept in perfect condition.

The best results have been obtained by keeping the temperature of the gas about 80 deg. fahr. The results will not change very much if the temperature ranges between 70 and 90 deg. fahr. The temperature can be controlled by running the hose through either hot or cold water.

The apparatus has one factor of error and that is the effects of water vapor. This can be checked by making a test, then distilling the sample of mineral seal oil. Distill sample and subtract water from the increase.

In over a hundred tests made with this instrument it was not found necessary to give water vapor any attention.

There are several of these outfits in use on the coast at this writing and their owners are meeting with good success with them.

In operating at 80 deg. fahr. and being violently agitated, the mineral seal has a tendency to throw off the higher series of hydrocarbons, such as butane, etc., which might otherwise upset the reading and also as the machine was calibrated from the plant production these series were originally taken care of.

SINGLE COIL ABSORBERS

The single coil absorber (1) shown in figures 30 and 31 is built on the principle of the Friedrich gas-washing bottle. It consists of two lengths of 4 inch pipe, "e" and "b," joined with ½ inch pipe and a coil of ¼ inch Shelby seamless tubing "f." The lower end of the ½ inch pipe extends into a 1¼ inch pipe as shown. The gas enters the absorber

through a ¼ inch pipe perforated inside the absorber with 1-32 inch holes.

In using this absorber, the ¼ inch plug at the top is removed and 1750 cc. of "mineral seal oil," accurately measured, is introduced. A pressure gauge is placed in the ¼ inch tap and connection made from the ½ inch valve at "e" to a gas meter.

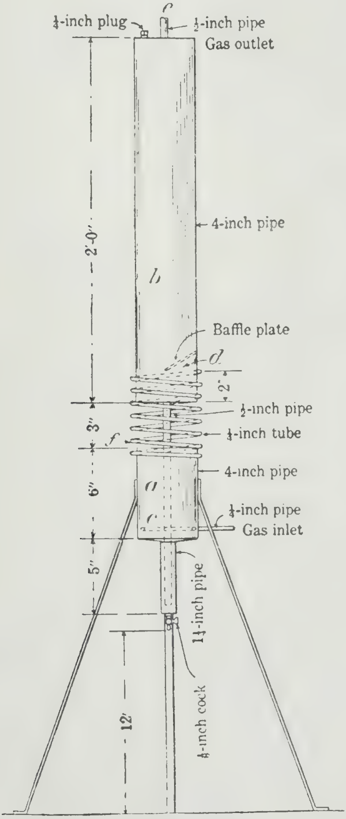


Fig. 30—PORTABLE ABSORBER FOR TESTING "DRY" NATURAL GAS FOR GASOLINE CONTENT

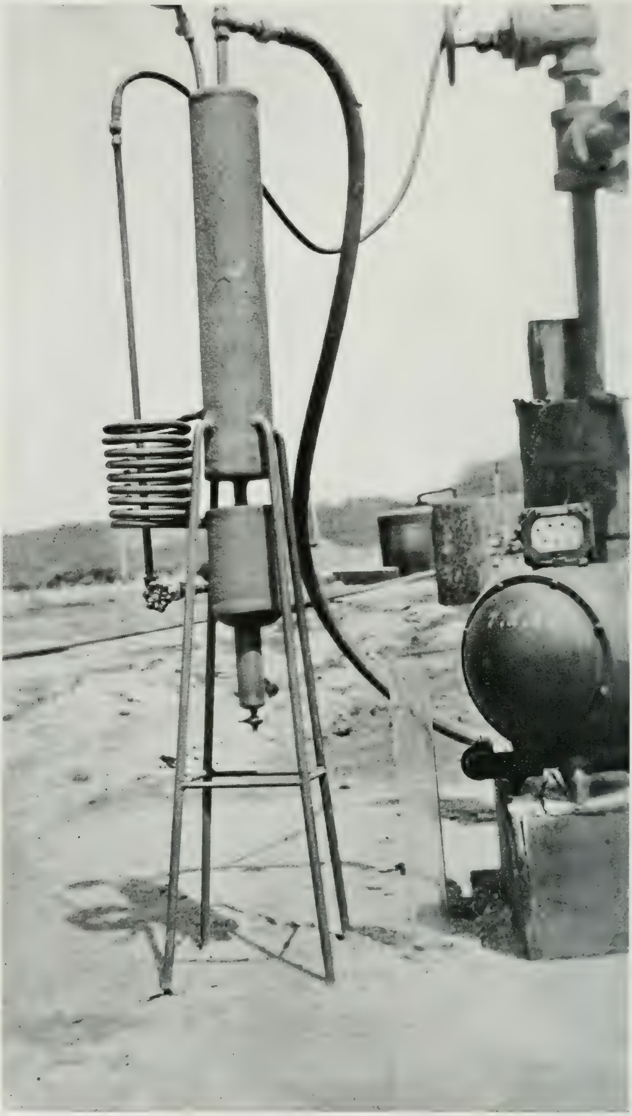


Fig. 31—PORTABLE SINGLE COIL TESTING ABSORBER CONNECTED FOR A TEST

The gas to be treated is connected to the ¼ inch gas inlet line. Valve at "e" is closed and the gas allowed to enter the absorber. When the pressure on the absorber reaches the point desired, the outlet valve at "c" connecting to the meter is slightly opened.

The gas entering the absorber, is broken up into fine streams, passes around the coil in intimate contact with the oil and out of the absorber to the meter. The oil is circulated by the gas from the reservoir "a" through the coil into reservoir "b," being deflected back by the baffle plate at "d" and passing into the lower compartment "a" through the ½ inch pipe.

A gas rate of 100 cubic feet per hour is satisfactory.

When the meter shows that the desired number of cubic feet, lacking about 2, have passed through the absorber, the inlet gas is shut off. The gas pressure in the absorber gradually falls. When down to atmospheric pressure, the meter is read and the difference between the initial and final readings gives the actual cubic feet passed, when corrected for temperature and pressure. Where the outlet gas is measured an allowance should be made for shrinkage in gas volume. It is preferable to measure the inlet gas.

The oil is withdrawn from the absorber, placed in tight stoppered, stout bottles, and sent to the laboratory for distillation.

FOUR COIL TESTING ABSORBER

An absorber similar in operation to Fig. 32 but having four contact coils is a highly efficient instrument for testing especially at low pressure. In effect it is four single coil absorbers connected in series. It is used on casinghead gas and other low pressure testing work. The method of handling is the same as for the single coil instrument shown in figure 31.

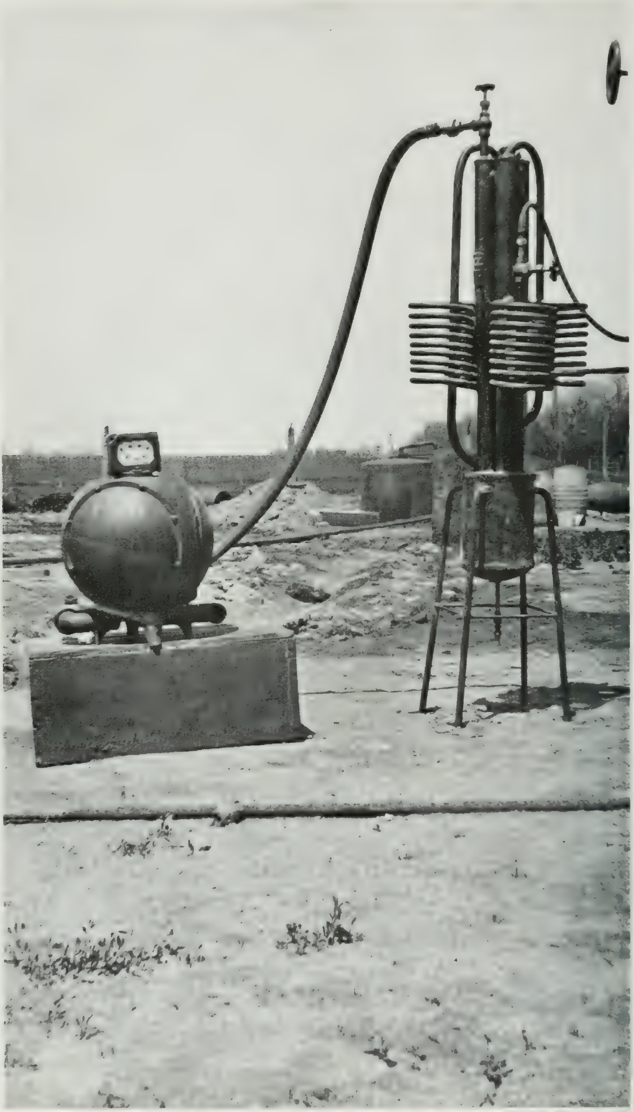


Fig 32—PORTABLE FOUR COIL TESTING ABSORBER CONNECTED FOR A TEST

PIPE ABSORBER

There is a type of test absorber in use by numerous gas companies where a gas contact coil is not used. The size used held a charge of 5000 cc. of "mineral seal oil." The apparatus is simple as can be seen from the drawing, Fig. 33. It consists of a piece of pipe with a ¼ inch gas inlet line leading to the bottom inside and ending in a circular coil perforated with fine holes. On the gas inlet line "d" a pressure gauge is placed. A plug on top of the absorber allows easy charging of the absorber. The gas outlet line at "c" connects to the gas meter. If desired, a slight pressure of say 4 to 6 inches of water on the guage can be carried on the meter by regulating the gas outlet valve on absorber and meter. With this data the gas passed can be corrected to standard conditions. Inlet gas should be metered or due allowance made for gas shrinkage.

The advantage of this apparatus over the single coil absorber as described (Fig. 31) is portability. The disadvantage is that it does not secure intimate, thorough contact between gas and oil such as is secured by the portable single coil absorber. The allowable saturations used with the single coil absorber with this type of apparatus will allow gasoline to escape.

In using the apparatus, it is charged with 5000 cc. of absorbent oil and connected to gas to be tested and meter. When the desired pressure is reached on the absorber as shown by the gauge, gas is allowed to pass to the meter and the pressure and temperature of gas at the meter noted. After passing the desired volume of gas, the inlet valve is closed, the absorber is allowed to drain of gas, and the final meter reading is taken.

The oil is either left in absorber with valve closed and sent to the laboratory for distillation or removed at once into tight containers if more than one test is to be run.

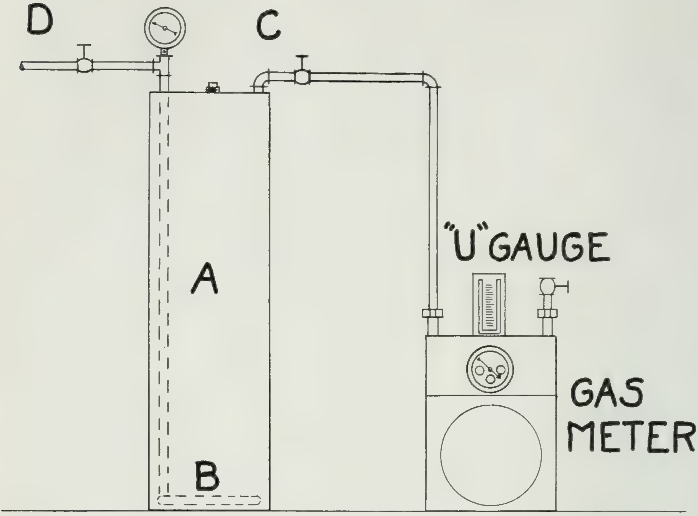


Fig. 33—FIRST ABSORBER

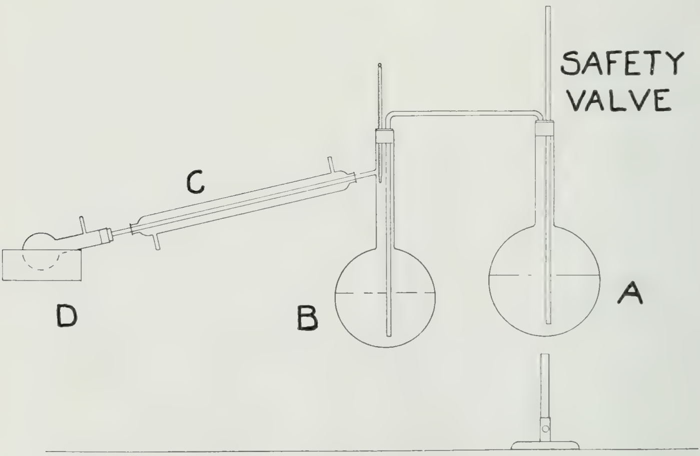


Fig. 34—STEAM GENERATING FLASK

If desired, two of these absorbers can be connected in series, thus cutting down the chances of gasoline escaping with the gas.

METHODS OF DISTILLING THE ENRICHED OIL SAMPLES

There are two methods in use for distilling the gasoline from the absorbent oil. Both have been tested very carefully and preference given as a result of these tests to the Fire Distillation Method. We have found that the objection to the steam distillation method lies in the "carrying over" of the lighter portions of the absorbent oil no matter how carefully the distillations are run. This is very noticeable when testing samples from gas containing little gasoline.

Steam Distillation Method—In the drawing Fig. 34, "a" is the steam generating flask holding about 1000 cc. of water, "b" is the oil distillation flask in which 1000 cc., carefully measured, of the enriched oil is placed, "c" is a Liebig condenser and "d" is the receiving flask surrounded by ice to prevent loss by evaporation during distillation. In distilling a sample of oil, water is placed in the steam generator flask and its boiling point determined by the thermometer used to determine later the end point of the oil distillation. We will say for instance that the reading was 98.5 deg. cent. This thermometer is then inserted in the oil distillation flask with the bulb slightly below the side vapor outlet. The steam generator is connected to the flask "b" containing the oil sample, and steam is passed through the oil until the thermometer registers 98.5 deg. cent. (The boiling point of the water used to generate the steam). At the end of the distillation the water and gasoline in receiver "d" are poured into a graduated cylinder and the volume of gasoline noted. From the volume of gasoline recovered, the volume of oil recovered from the absorber, and the number of cubic feet of gas passed through

the oil, the gasoline content of the natural gas can be figured to pints per thousand, or gallons per million cubic feet of gas.

Effect of Pressure on Absorption—The results of experiments conducted using 3 absorbers (similar to figure 31) connected in series, shows that in the absorption of gasoline from natural gas, the volume of gasoline which "mineral seal oil" will absorb varies directly with the pressure. From similar tests it has been demonstrated that the amount of oil required to extract a given quantity of gasoline varies inversely as the absolute pressure. These are not discoveries. They merely demonstrated Henry's law of gases which has been well known by physicists for over a hundred years.

Limits of Saturation—The following table shows the allowable saturations at different pressures of "mineral seal oil" in testing with the coil type of absorber.

Allowable Saturation in Absorption Tests with Single Coil Absorber

Atmospheric Pressure—Use at least 2 absorbers in series and do not allow saturation in first absorber to exceed	0.27 per cent.
15 Pounds Pressure—Use one or two absorbers in series. Do not allow saturation in first absorber to exceed	0.55 " "
30 Pounds Pressure—One absorber. Saturation not over	0.82 " "
70 Pounds Pressure—One absorber. Saturation not over	1.57 per cent.
125 Pounds Pressure—One absorber. Saturation not over	2.60 " "
200 Pounds Pressure—One absorber. Saturation not over	4.00 " "
300 Pounds Pressure—One absorber. Saturation not over	5.85 " "
400 Pounds Pressure—One absorber. Saturation not over	7.20 " "

If, upon distillation, the absorbent oil is found to exceed these figures, the resulting figures of gasoline yield will be found to be too low and new runs should be made to come within the saturation figures given. (By saturation is meant the ratio of gasoline absorbed to oil used as absorbent.)

DYKEMA ABSORBER*

"Methods for determining the gasoline content of gas have been considered in several Bureau of Mines papers.† Tests of small samples of gas by specific gravity determination, change in volume of gas in contact with an absorption medium, or increase in volume of absorption menstruum, merely indicate the quantity of gasoline in the gas and often

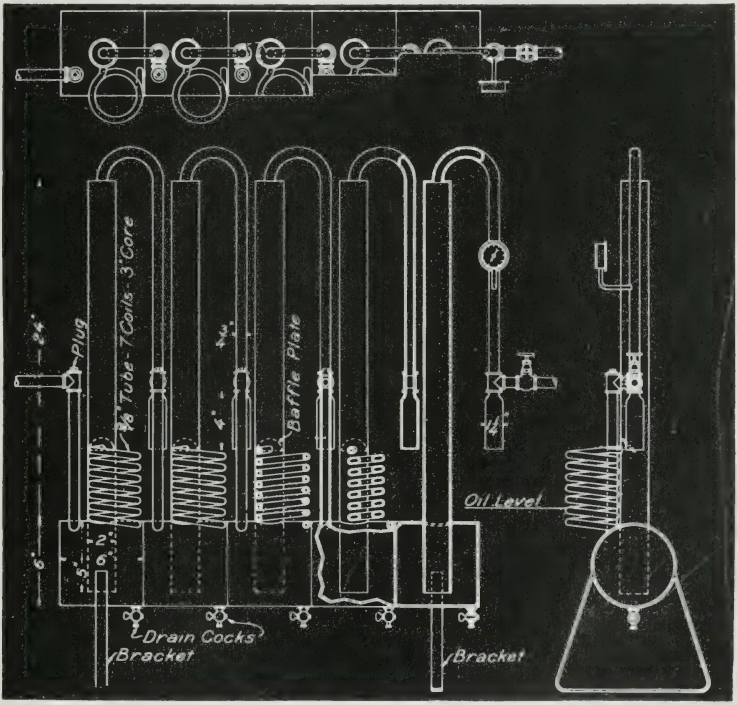


Fig. 35—THE DYKEMA ABSORBER USED FOR DETERMINING THE GASOLINE CONTENT OF "LEAN" NATURAL GAS OR CASINGHEAD GAS

* By W. P. Dykema and R. O. Neal.

† Bulletin 88, Condensation of gasoline from natural gas. Bulletin 120, Extraction of gasoline from natural gas by absorption process. Bulletin 151, Recovery of gasoline from natural gas by compression and refrigeration. Tech. Paper 87, Methods of testing natural gas for gasoline content.

lead to ambiguous results. The only accurate method of determining the gasoline content of gases that contain less than a gallon of gasoline per thousand cubic feet is to allow a given quantity of the gas to come in contact with some absorption medium and to separate the absorbed gasoline from the oil by distillation. The method outlined in this paper is effected by using an absorption apparatus that differs somewhat in design from any previously described, although it embraces the same principle of operation—that of the Friedrich's wash bottle. This absorber has the advantage of being a rigid unit, with a large capacity for oil and consequently a larger gas capacity. By using larger volumes, more representative determinations can be made and the opportunities for error are materially decreased. This type of tester is also adapted to plant efficiency, control being used in parallel with the plant in 24 hour runs on both incoming and residual gases.

Before the plant for recovering gasoline from natural gas is constructed, the quantity and quality of the gas to be used should be thoroughly examined. Often one sees plants that, because of the lack of adequate testing of the gas, were erected only to be abandoned as complete failures after a short period of operation. At present, there is no excuse for such conditions existing as a result of inadequate preliminary examination of the gas to be treated. Too much emphasis cannot be placed upon the importance of testing gas before the construction of a plant is planned.

The apparatus shown in Fig. 35 consists of a piece of 6 inch casing with five separate compartments, each of which is connected with a $\frac{3}{4}$ inch gas inlet and also with a 2 inch gas discharge pipe or separate chamber which extends to a point near the bottom of the casing. From the casing runs a $\frac{3}{8}$ inch pipe coiled around a 3 inch core with 7 turns, through which the gas being treated bubbles and in which most of the absorption takes place. Some small modifications and

additions, optional in the design, are not shown in the sketch, the use of needle valves at each extremity of the apparatus, in order that gas may not be introduced too rapidly (especially when making an examination of a high pressure gas) or may be throttled to any desired pressure so as not to carry oil over from one compartment to the next, also the use of a needle valve on discharge end to enable one to regulate more easily the rate of flow through the meter, especially in tests at low pressure, that is, when the gas flows through the absorber very slowly. It is advantageous to use gate valves instead of drain cocks for drawing off treated absorption oil from the oil chambers, as such valves facilitate rapid work and eliminate the possibility of volatilization losses when oil is allowed to spray through a stop-cock under pressure into the container for collecting treated oil. Also, time can be saved by using small bull-plugged nipples on the oil charging pipes in place of standard plugs, as they can be more easily removed and more rigidly connected to prevent leaks.

To make the test with this absorber, 2700 cc. of mineral seal oil, or enough to bring the level of the oil about 2 inches above the top of the 6 inch casing and well above the coil inlet, is accurately measured and introduced into each compartment. The most important requisite for absorption media is high initial boiling-point, in order that in the subsequent distillation, a quantative separation can be effected. The oil used in the tests described in this paper had the following physical properties:

Gravity	36.0 deg. B.
Initial boiling point	450 deg. fahr.
Viscosity at 70 deg. fahr.	51 Saybolt
Flash point (Pensky-Martens closed test)	271 deg. fahr.
Fire test (Pensky-Martens open test)	307 deg. fahr.

In most tests only the first three absorbers are used but it may be expedient to fill the fourth compartment when examining rich gases at low pressures or when running a large volume of dry gas in paralleling a 12 hour, or day's operation

of an absorption plant to determine the extraction efficiency. The fifth division is not intended to be used as a container for oil, but to serve as a separator or oil trap in case any oil is carried over from the preceding compartment. A meter capable of measuring from 1 to 1,000 cubic feet of gas accurately is connected to the discharge of the absorber.

The gas to be tested is allowed to slowly enter the apparatus with the discharge valve closed, and when pressure equilibrium with the gas to be examined is obtained, or when the desired pressure is attained, the discharge valve is opened enough to permit the desired rate of flow through the meter.

The gas entering the absorber bubbles up through the oil, the latter absorbing the gasoline. The function of the pipe coil is to provide a long and intimate contact between the oil and the gas as the gas passes through the absorber.

After the desired quantity of gas has passed through the absorber the supply is shut off and the pressure is released, through the needle discharge valve, allowing all the gas to flow through the meter. After the pressure has decreased to atmospheric pressure, all of the oil is withdrawn through gate valves at the bottom of the casing and the oil from each compartment is accurately measured, 1000 cc. of treated oil from each compartment being kept for distillation.

Distillation of Saturated Oil—Of the treated oil 400 cc. is introduced into a 500 cc. Engler distilling flask connected to a condenser made of ½ inch brass tubing and surrounded by cold (iced) water contained in a metal box.*

The flask is heated by direct fire, slowly at first, and the gasoline driven out of the oil is collected in a 25 or 50 cc. graduated cylinder, which should be surrounded by ice to eliminate the evaporation losses. The flask is heated until the vapor reaches a temperature of 350 deg. fahr., which usually requires 20 minutes. If the oil has a very high saturation, it is allowed to cool 20 to 30 deg. and again raised

* Am. Soc. Test. Mat. Year Book, 1915, pp. 568-569, and 1916, Vol. 16, pp. 518-521.

to 350 deg. This procedure is followed until practically no more gasoline is driven over and collected from the condenser. Great care must be taken in reaching 350 deg., the ring of mineral seal-oil condensed in the neck of the flask must never be allowed to reach the delivery tube.

The extraction of gasoline by the oil will depend upon the rate of flow, gasoline content of the gas, volume of gas treated, pressure and the temperature of the absorbing oil. Optimum conditions, as regards volumes of gas and rate of flow with gases at different pressures and gasoline content, are given below.

Table 42

CONTROLLING FACTORS IN OPERATION OF TEST ABSORBER

Maximum rates of flow of gas. Cu. ft. per hour	Pressure Lb. per sq. inch
400	300
200	150
100	75
50	40
20	Atmospheric

Table 43—MAXIMUM GAS CAPACITY

Cu. ft. of Gas	Gasoline—gal. per 1000 cubic feet
800	.125
400	.250
200	.50
150	.75
100	1.00
66	1.50
50	2.00
35	3.00
25	4.00

The following data were obtained from a representative test made upon the intake gas at a compression plant in the Mid-Continent field.

Temperature of oil	94 deg. fahr.
Pressure	204 lb.
Rate of flow of intake gas	133 cu. ft. per hr.
Volume of intake gas	302 cu. ft.

Table 44

	Compartments		
	1st	2nd	3rd
Charge	2600 cc.	2600 cc.	2600
Recovered	2700	2600	2630
Gravity of oil	37.0 deg. B.	36.4	36.0
Distilled	400 cc.	400	400
Initial C. B.	170 deg.fahr.	185	308
Gasoline	19.5	9.5	3.5
Total each	131.5 cc.	63.2	23
	217.7	cc. 78 deg.	B.gravity.
Proportion extracted in each compartment	60.5 per cent	29.0 per cent	10.5 per cent
Gasoline content	0.190 gal.	per 1000	cu. ft.

The gasoline content is calculated by using the following formula:

$$Q = \frac{1000}{G} \times \frac{C}{3785}$$

where Q is the gasoline content in gallons per 1000 cubic feet of gas, G is the volume (cubic feet) of gas treated, and C is the total number of cubic centimeters of gasoline obtained from the treated absorption medium, based on the quantity of oil taken out of the absorber.

The temperature, above certain limits, of the absorbing oil has probably more effect on the efficiency of extraction than any other factor. In a series of tests of dry gas with all conditions constant, except the variable factor of temperature a difference of 42 per cent in the volumetric recovery of

gasoline for gradient of 30 deg. fahr. was obtained, as is shown by the curve in Fig. 36. These changes took place between 90 deg. fahr. and 120 deg. fahr. and are undoubtedly due to the rapid increase in the partial vapor pressure of the gasoline fractions in the gas as their boiling points are

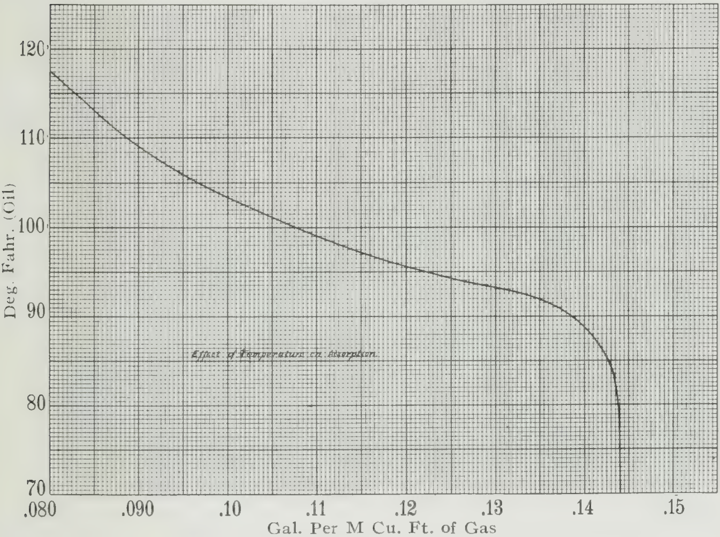


Fig. 36

reached. The gas at 70 deg. fahr. contained .144 gallons per thousand cubic feet of gas and this figure is taken as 100 per cent as shown on the curve. Probably no two gases will show the same results with the same variation in temperature, inasmuch as the characteristics of the gasoline hydrocarbons are distinctly dissimilar. The data from which this curve was plotted were obtained from a series of tests using a constant quantity of oil (2700 cc. of oil in each of the first three compartments), a pressure of 130 pounds per square inch and a total volume of gas of 200 cubic feet which passed through the apparatus at the rate of 2 cubic feet per minute.

The data obtained in this test are not a criterion by which to judge other gases, as cognizance must be taken of the fact that although gases may have the same gasoline content still the characteristics of the various hydrocarbons contained will be altogether different and consequently will require different operation methods and give varying results under test such as the above.

The test absorber and the method described in this paper is recommended in preference to the use of those scrubbers mentioned in other publications because it gives more significant results when evaluating a gas with the idea of determining the feasibility of installing an absorption gasoline plant, or of ascertaining the efficiency of extraction at absorption or compression gasoline plants."

Test of Casinghead Gas with the Dykema Absorption Tester

Pressure .... 15 lb.
Volume .... 52.7 cu. ft.
Temperature of oil .... 97 deg. fahr.

	Compartments			
	1st	2nd	3rd	4th
Charge	3000 cc.	3000 cc.	3000 cc.	3000 cc.
Recovered	3100	3050	3000	3000
Distilled	400	400	400	400
Gasoline	4.5	4	3.5	2.00
Total gasoline each	34.87*	30.5*	26.25	15.00
Grand Total	106.62 cc.			
Proportion extracted in each compartment	32.70 per cent	28.60 per cent	24.62 per cent	14.07 per cent
Gasoline content	.53 gal. per thousand cubic feet.			

Tested by: R. O. NEAL and D. B. DOW.

* Due to high working temperature, saturations in first two compartments became approximately equal. This is unusual under average testing conditions.

CHARCOAL ABSORPTION TESTING APPARATUS*

Oberfell Gas Testing Apparatus—This apparatus has been developed for the determination of the volume, specific gravity, and gasoline content of natural gas and while designed more especially for use in testing natural gas, it can be used for similar purposes with other gaseous mixtures.

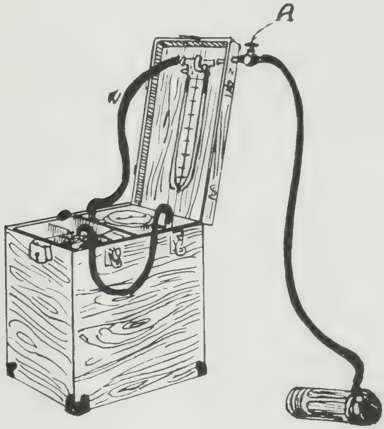


Fig. 37

The principle of this method of testing natural gas for gasoline content, consists in absorbing the gasoline vapors in highly activated charcoal, and subsequently recovering the gasoline by distillation.

The equipment required for the determination of the volume, specific gravity and gasoline content of the gas, is contained in one case, forming a convenient portable apparatus with sufficient material for eight tests. The time consumed by this method in absorbing the gasoline vapors from casinghead gas, is about 30 minutes. This method is applicable to rich and lean natural gas and can be used in tests of gas at pressures higher than atmospheric.

* By G. G. Oberfell.

The case as shown in Fig. 37 contains the following material:

A dry test meter with a capacity of 15 to 30 cu. ft. per hour at $1\frac{1}{2}$ inches water pressure ; eight absorbers filled with activated charcoal, connection caps for absorbers, and small orifice flow meter used in controlling the rate of flow of gas through the dry test meter and in determining the specific gravity of the gas. In addition to this special equipment the case contains an orifice well tester, orifice plates, stop watch, note book, thermometer, and necessary rubber tubing.

Determination of Densities—In determining the specific gravity or density of gas at a well, use an orifice plate in the well tester which will give a pressure drop through the orifice of about 8 inches of water. The needle valve at "A" is then closed and the flow meter is connected by rubber tubing, with the well tester on the one side and with the dry test meter on the other side. The needle valve is then slowly opened until a constant differential pressure of six inches or more is indicated on the "U" tube of the flow meter. This differential pressure through the flow meter is regulated by the needle valve at "A". The time required for the passage of a definite volume (usually about one-half cubic foot of gas) through the dry test meter is noted. The flow meter is then disconnected from the gas supply and the time required for the passage of an equal quantity of air under the same experimental conditions is noted. The latter value may be obtained, if no other means are available, by blowing one-tenth of a cubic foot of air from the lungs through the apparatus, noting the time and multiplying the result obtained by five, if gas time was recorded upon the passage of $\frac{1}{2}$ cu. ft. of gas. With a little practice a person can perform this operation, and a good value for the time for air passage may be obtained by averaging the results of several determinations. The carbon dioxide and moisture in

the air from the lungs may be removed by a tube filled with soda line or resulting error, (which may be neglected for most purposes) may be taken into consideration in calculating the specific gravity of the gas. The specific gravity of the gas is calculated as follows:

$$\text{Specific gravity of gas} = \left(\frac{\text{Time for gas flow}}{\text{Time for air flow}}\right)^2$$

Fig. 38—ABSORBER AND CONNECTION CAP

Gasoline Content—The absorber (Fig. 38) is a metal tube fitted near one end with a perforated disc, which serves as a support for the charcoal. The tube is rendered gas tight by means of the screw caps which are fitted with rubber composition gaskets.

The absorber is filled with highly activated charcoal, gently tapped to constant volume and then completely filled. Just before using for the absorption of gasoline vapors the tube should again be gently tapped. The

success of this method depends upon the quality of charcoal used as an absorbent which should meet the requirements of a standard test for activated charcoal.

Charcoal exposed to air takes up large quantities of moisture which impairs its value as an absorbent, therefore it should be carefully preserved in air-tight containers.

The percentage of moisture may be readily determined by adding 100 cc. of naphtha, kerosene, or heavier distillate to 250 cc. of charcoal and distilling off the water. The distillation apparatus described below may be used for this test. The percentage of water by volume is calculated as follows:

$$\text{Percentage Moisture} = \frac{\text{cc. water removed}}{\text{cc. charcoal used}} \times 100$$

or for 250 cc. of charcoal the following formula is used:

$$\text{Percentage of Moisture} = \text{cc.} \frac{\text{Water removed}}{2.5}$$

The apparatus is again connected to the gas supply as described for determining the specific gravity of the gas, the needle valve at "A" being closed. A short piece of rubber tubing is then attached to the outlet of the dry meter and about 2 cu. ft. of gas passed through the meter in order to expel the air or gas from previous tests. The needle valve is then closed, an absorber removed from one of the compartments, the caps removed from the ends of the tube, one being replaced by the special cap, (Fig. 38 "B") and connections made between the dry test meter outlet and the absorber. The absorber should be placed in a vertical position during the test.

Be sure that the gas supply represents the gas which it is desired to test, in that the conditions at the time of test should be such that a representative sample of the gas is obtained. The pressure on gas wells or oil wells, and the conditions under which the wells are normally operated should be carefully considered before making the test. Pressure on wells will

in practically every case, cause low gasoline yields, while a vacuum will have a tendency to increase the gasoline content of the gas. The writer knows of one instance where a pressure of 20 lb. at the casinghead as compared with atmospheric pressure, decreased the gasoline content of the gas 40 per cent.

Frequently tests taken just after blowing a gas well for several hours or taken just after pumping or flowing of oil wells, will show results higher than should be expected under normal conditions. There is frequently a greater source of error in the method of taking the sample of gas than there is in the method of determining its gasoline content by this apparatus.

Fig. 39

A measured quantity of gas is then passed through the charcoal at about atmospheric pressure, rate of flow being regulated by valve "A". The gas flow is then stopped, ab-

sorber disconnected, and a slip of paper, containing data for identifying sample, placed in the end of the absorber, between the perforated disc and cap. The caps are then screwed on the absorber and the absorber, containing the charcoal enriched with gasoline vapors, is sent to the laboratory for the determination of the gasoline content of the gas as described below.

No trouble due to leaks should be experienced with this apparatus owing to the low pressure at which it is operated. However, due precaution should be taken to see that the system is free from leaks during a test.

Table 45—APPROXIMATE AMOUNT OF GAS TO USE IN A TEST OF NATURAL GAS BY CHARCOAL TESTING METHOD

Specific Gravity	Cu. Ft. to Use	Specific Gravity	Cu. Ft. to Use
0.60	125.0	0.84	4.3
0.65	20.0	0.85	4.1
0.66	17.4	0.86	4.0
0.67	14.7	0.87	3.8
0.68	13.2	0.88	3.7
0.69	11.4	0.89	3.6
0.70	10.3	0.90	3.5
0.71	9.3	0.95	3.0
0.72	8.6	1.00	2.6
0.73	8.0	1.05	2.3
0.74	7.3	1.10	2.1
0.75	6.9	1.15	1.9
0.76	6.5	1.20	1.7
0.77	6.2	1.25	1.6
0.78	5.8	1.30	1.5
0.79	5.5	1.35	1.4
0.80	5.2	1.40	1.3
0.81	4.9	1.45	1.2
0.82	4.7	1.50	1.2
0.83	4.5		

If no information other than specific gravity is available for estimating the gasoline content of the gas, it is advisable to run duplicate tests, using volumes 1/3 less and 1/3 greater, than those recommended in this table, since yields estimated from gas density alone may be several hundred per cent in error.

The amount of gas passed through the charcoal should be such that a volume of about 25 cc. of gasoline will be obtained upon distillation of the enriched charcoal, when using charcoal of approved quality. If no other source of information is available, the specific gravity of the gas will afford some idea of the amount of gas to use for a test. In such case reference may be had to the table accompanying the apparatus.

The rate at which gas should be passed through the charcoal during tests of lean gas is limited by the capacity of the dry test meter. This rate is about 15 to 30 cubic feet per hour, allowing a reasonable overload. In no case should the gas rate be so great that the test is completed in less than about thirty minutes. It is also advisable to pass the gas slowly enough so as to have a part of the charcoal cool during the entire test. The heat will first be apparent where the gas comes into first contact with the charcoal. The zone of heat will then gradually travel along the tube, leaving cool the layer of charcoal of first contact with the gas, and thereby increasing the absorption capacity of the charcoal and effecting a more complete removal of the stable hydrocarbons.

Distilling Gasoline from Charcoal—The most satisfactory method for removal of gasoline from the enriched charcoal consists in adding 125 cc. of glycerin to the charcoal in a flask and distilling off the gasoline. It is advisable to distill off from the glycerin before using it, that portion boiling below 500 deg. fahr. This operation will remove most of the water that would be condensed during distillation of gasoline from enriched charcoal. If desired, Mineral Seal Oil may be used instead of glycerin. Cresol may also be used. Any cresol which is carried over during distillation may be removed from gasoline by washing it with a solution of sodium hydroxide.

The distillation apparatus consists of:

2 Flat base ring stands.
2 5 inch rings.
1 Burner platform.
1 No. 2 high temperature burner.
1 5 inch square asbestos millboard.
12 foot ¼ pure gum tubing.
1 1000 cc. round bottom boiling flask.
1 50 cc. graduate.
1 1000 cc. beaker.
1 500 cc. Ehrlemeyer flask.
1 1428A distillation thermometer 20-520 fahr.
1 12x¼ inch glass tube.
1 assortment rubber stoppers.
1 jacketed condenser with circulating device.
3 2x2x$\frac{5}{16}$ inch copper ells.
1 4x2x$\frac{5}{16}$ inch copper tee.
1 $\frac{5}{16}$ inch copper vapor tube.
1 copper absorber.
1 78-80 deg. B. hydrometer—4 inch Tycos.
1 80-90 deg. B. hydrometer—4 inch Tycos.

The rate of distillation should be such that about 45 minutes are required to complete the distillation. The vessels surrounding the receiving cylinder and the condenser tube should be filled with an ice water mixture. The ice and water in the condenser should be stirred frequently in order to insure complete condensation of gasoline. Failure to observe these instructions is likely to result in low gasoline yields. If desired a mechanically agitated device may be readily installed by surrounding the condenser tube by a cylinder open at both ends. Air or gas may be caused to bubble through the water between the cylinder and the condenser tube thereby circulating the water and maintaining a temperature of 32 deg. fahr. for the water surrounding the condenser tube

The distillation is stopped at 500 deg. fahr. most of the gasoline being removed from the charcoal below the temperature of 250 deg. fahr.

The addition of glycerin to the charcoal is frequently accompanied by a little foaming. This difficulty is overcome by heating slowly at first and by shaking the flask. This latter operation can be accomplished without breaking connections between the flask and the condenser.

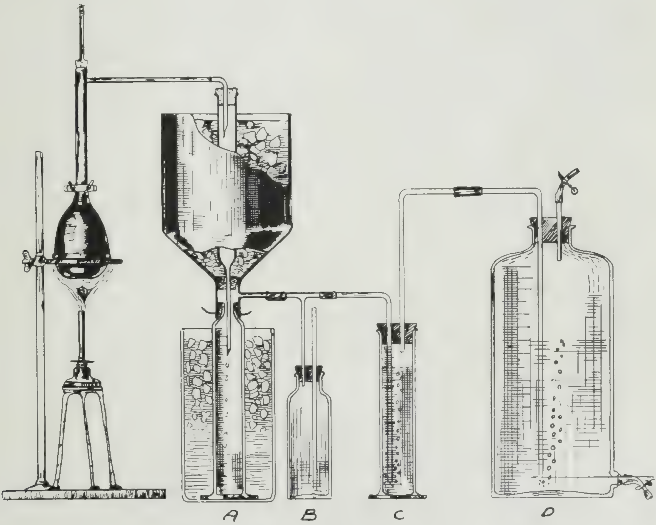


Fig. 40—DISTALLATION APPARATUS USED WITH CHARCOAL TESTING APPARATUS

In case the distillate is less than 15 cc. from 250 cc. of approved quality charcoal, a low saturation of charcoal with gasoline has been obtained. It frequently happens that a low saturation of charcoal is accompanied by the evolution of a large quantity of vapors that cannot be condensed at the temperature of the condenser bath. These vapors that are not condensed carry over with them some of the less

volatile vapors. In order to eliminate this error it is advisable to use results of tests of the higher saturation only. If this cannot be done it is advisable to pass the vapors that are not condensed through a condenser tube surrounded by a carbon dioxide acetone bath or through about 50 cc. of naphtha in a graduated cylinder. The gravity and volume of naphtha is determined before and after the test at 60 deg. fahr. The gravity and volume of condensate are also determined and the condensate added to the enriched naphtha. The blend is then weathered so that the gravity of the gasoline alone in the blend will correspond to that which falls within the ten pound vapor tension limit for gasoline from the gas in the locality from which the test is taken.

The modification of distillation method in which the non-condensable vapors are passed through naphtha affords an opportunity to control the rate of distillation, while the pressure introduced aids materially in condensing the more volatile vapors. This modification which has proven very beneficial in the oil absorption method, was devised by P. M. Biddison and C. L. Voress.

If desired, two charcoal tubes may be used in series during the absorption of gasoline vapors from the gas. In such case the charcoal from the tube of first contact with the gas is subjected to distillation first and those vapors which are not condensed are passed through the enriched charcoal in the tube which had been placed second in contact with gas. The charcoal from the tube of second contact with gas is then subjected to distillation. Such a procedure allows a higher saturation in the first tube, cuts down distillation losses and permits the use of charcoal of poorer quality than could otherwise be used.

Another modification of the distillation method which has met with success in cutting down distillation losses in removing gasoline from charcoal of low saturation with

gasoline, consists in using part of the enriched charcoal from the tube as a filtering column which is placed in the neck of the distillation flask. The filtering column of enriched charcoal is supported by means of a screen, which, in turn, is supported by a wire extending through the stopper in the flask. This column of charcoal, as above stated, acts as a filtering agent and thereby removes the heavier hydrocarbons which might otherwise be lost during the first part of

Table 46

MULTIPLYING FACTORS FOR CONVERTING YIELD OF OBSERVED GRAVITY TO YIELD OF DESIRED GRAVITY

Desired Gravity deg. B.

Observed Gravity deg. B.	84	85	86	87	88	89	90	91	92
95	.480	.515	.545	.580	.610	.645	.690	.735	.785
94	.520	.555	.590	.625	.665	.705	.755	.805	.860
93	.565	.600	.640	.680	.720	.760	.815	.870	.930
92	.610	.650	.690	.730	.770	.820	.875	.935	1.000
91	.655	.695	.740	.780	.830	.880	.940	1.000	1.070
90	.700	.740	.785	.830	.880	.940	1.000	1.065	1.145
89	.745	.780	.835	.885	.940	1.000	1.065	1.140	1.215
88	.790	.835	.890	.940	1.000	1.060	1.135	1.210	1.295
87	.840	.885	.945	1.000	1.060	1.125	1.200	1.285	1.375
86	.890	.940	1.000	1.060	1.125	1.195	1.275	1.360	1.460
85	.945	1.000	1.065	1.125	1.195	1.265	1.355	1.445	1.550
84	1.000	1.060	1.125	1.195	1.265	1.345	1.435	1.530	1.640
83	1.060	1.125	1.195	1.265	1.340	1.420	1.515	1.620	1.735
82	1.125	1.195	1.265	1.340	1.420	1.500	1.600	1.715	1.830
81	1.195	1.265	1.340	1.420	1.500	1.590	1.695	1.815	1.940
80	1.265	1.340	1.420	1.500	1.590	1.680	1.790	1.920	2.050
79	1.340	1.420	1.500	1.590	1.680	1.770	1.895	2.025	2.170
78	1.420	1.500	1.600	1.685	1.780	1.870	2.000	2.140	2.295
77	1.505	1.600	1.695	1.785	1.880	1.980	2.120	2.265	2.430
76	1.595	1.695	1.795	1.895	1.995	2.090	2.240	2.400	2.580
75	1.690	1.790	1.900	2.000	2.105	2.205	2.380	2.550	2.740

the distillation. After a few cc. of gasoline has been obtained in the receiving cylinder, the column of charcoal is gradually dropped into the flask, by lowering the screen support, this latter operation being performed by pushing the wire which extends through the stopper in the distillation flask. The distillation is then completed in the usual manner:

Each of the modifications mentioned above have tended to increase the accuracy of the distillation method. The latest modification devised by the writer and used at the present time, is carried out as follows: About 50 cc. of the enriched charcoal is poured into an empty absorber. The remainder of the enriched charcoal is poured into the flask 125 cc. of glycerin added, and the distillation carried out in the usual manner. The vapors not condensed during this distillation are passed directly through the absorber containing the 50 cc. of enriched charcoal. When a temperature of 500 deg. fahr. as shown by thermometer in the flask, has been reached, the flame is removed and the flask allowed to cool for about five minutes. About 60 cc. of glycerin are poured into the flask. The 50 cc. of enriched charcoal are placed in a hollow cylinder made of filter paper, the cylinder containing the charcoal is dropped into the flask, and the flask again heated to 500 deg. fahr. Naphtha need not be used in this method of distillation. In taking the absorption test in the field, it is advisable to pass the gas from the bottom upward through the tube, so as to have the charcoal of lower saturation at the top of the tube. The 50 cc. of charcoal poured out of the top of the tube for this method of distillation will then represent charcoal of lower saturation.

This latest distillation method can be carried out very rapidly. The gasoline from the first charge of charcoal may be distilled as fast as desired, since the stable vapors which are not condensed are absorbed in the charcoal which is later used for the second charge. The time required for dis-

tilling the gasoline from both charges of charcoal need not exceed thirty minutes. This modification when used in distillations carried out under a pressure of about 5 to 15 lb. increases the yield considerably and at the same time gives a product of greater volatility as would be expected. When the distillations are carried out under pressure, it is necessary to use a metal (preferably copper) distillation flask.

The greatest chances for improving the accuracy of the charcoal testing method lies in the possibilities of improvements in the methods of distilling the gasoline from the charcoal. The charcoal testing method has in all comparative tests shown a greater yield of gasoline, considering gravity, distillation loss, vapor tension, and weathering loss, than any other direct testing method when the tests were properly conducted, but the method does not show the maximum amount of salable product obtainable by plant practice (see Page 183).

Absolute alcohol may be used as a solvent for vapors that do not condense during distillation. The vapors are passed through two 50 cc. cylinders in series in an ice salt water bath, each cylinder containing 25 cc. of absolute alcohol accurately measured. The gasoline extracted from the vapors will separate from the alcohol upon addition of water. The cylinders should be about 9 inches high and graduated to $\frac{2}{5}$ of a cc. Absolute alcohol can be obtained sufficiently pure for this test by distilling denatured alcohol over dry activated charcoal and quicklime. This method gives a much higher yield but the total condensate generally weathers to the same volume as obtained without this modification.

Vapor Tension and Gravity of Gasoline—This apparatus (not supplied with outfit) consists of a mercury manometer made of 1 to 3 m. m. capillary tubing and a 25 cc. graduated cylinder. The cylinder containing the condensate is attached to a manometer by means of a rubber stopper or by means of a cork stopper and Kotinksy cement.

(A suitable cement may be made by mixing shellac and pine tar.) The air is purged from the apparatus by lowering the sliding reservoir and allowing vapors to bubble up through the column of mercury. The amount of pressure is controlled by the height of the mercury column. The leveling bulb serves the purpose of setting the "relief" at any desired pressure. The vapor tension reading should be taken with the relief set at a pressure only slightly greater than that shown on the U tube.

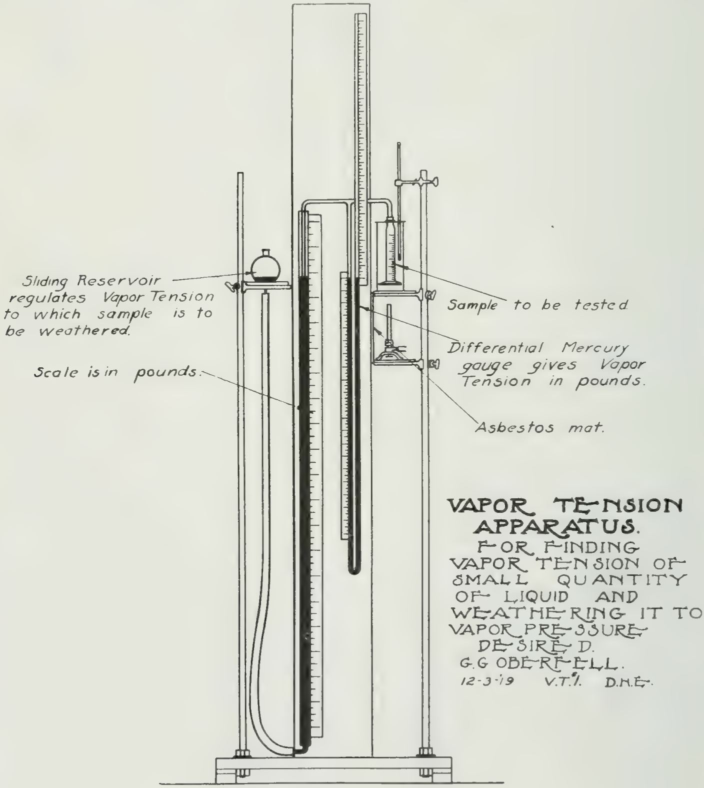


Fig. 41

In case the distillate has a vapor tension of less than 10 pounds per sq. in. at 100 deg. fahr., the saturation of the charcoal with gasoline has probably been too high. This frequently occurs if the distillate from 250 cc. of approved quality charcoal is in excess of 35 cc.

The gravity of the gasoline is taken, according to the prescribed methods, * by means of a small hydrometer. A four inch Tycos hydrometer will give very satisfactory results. The gravity and yield is determined on the gasoline remaining in the cylinder after the product has been weathered to a ten pound vapor tension at 100 deg. fahr. or after weathering to any desired temperature at atmospheric pressure. (See "Regulations to Govern the Utilization of Casinghead gas Produced From Oil Wells on Restricted Indian Lands", and "Regulations of the Interstate Commerce Commission for Transportation of Explosives and other Dangerous Articles by Freight and by Express.")

If a large number of tests are made of gas in one locality it is not necessary to weather condensate from each distillation to a ten pound vapor tension product, since the average gravity for the results of several tests may be taken as representing the gravity of the ten pound vapor tension gasoline from that locality.

Calculations.

The yield of gasoline is calculated from the following formula in which

G. P. M. = Gallons of gasoline per thousand cubic feet of gas (at temperature of 60 deg. fahr. and pressure of 30 inches of mercury.)

One U. S. Gallon = 3785 cubic centimeters.

A = Volume in cubic feet (at temperature of 60 deg. fahr. and pressure of 30 inches of mercury) of gas passed through the charcoal.

* U. S: Bureau of Standards Circular No. 57. United States Standard Tables for Petroleum Oils.

B = Volume in cubic centimeters (at temperature of 60 deg. fahr.) of gasoline distilled from the charcoal.

$$\text{G. P. M.} = \frac{B \times 1000}{A \times 3785} \text{ or}$$

$$\text{G. P. M.} = \frac{.2642\ B}{A}$$

The table on page 186 prepared by Mr. C. L. Voress, will find ready use in calculating gasoline yields. To calculate yields multiply the volume in cubic centimeters of gasoline obtained from the charcoal by the factor in the column opposite to the volume, in cubic feet, of gas used in the test. The result obtained by using this table is in gallons per million.

e. g. 51 cubic feet of gas were used.
25 cubic feet of gasoline were obtained.

Refer to column two, row one. The factor is 5.1817.

Therefore the yield is 5.1817 x 25 = 130 gallons per million or 0.130 G. P. M.

The factor for 5.1 cubic feet would be 51.817, as will be readily understood.

Gravity of raw gasoline in a blend is calculated as follows, in which:

V_b = Volume in cubic centimeters of blend.
V_n = Volume in cubic centimeters of naphtha.
V_g = Volume in cubic centimeters of gasoline. (Increase in volume of naphtha.)
G_b = Specific gravity of blend.
G_n = Specific gravity of naphtha.
G_g = Specific gravity of gasoline

The temperature of 60 deg. fahr. is taken as basis for volume and gravity determination

$$G_g = \frac{V_b\ G_b - V_n\ G_n}{V_g}$$

The gravity of gasoline corresponding to degrees B., may be obtained by reference to tables in U. S. Bureau of Standards Circular No. 57 **United States Standard Tables for Petroleum Oils.** See Part 19.

Table 46 page 171 is intended for use in correcting volumes of gasoline of known gravity to volume of another gravity, which may be desired as a basis for reporting results of tests for gasoline yield. The table may be used for correcting yields if the gravity of the gasoline distilled from the charcoal does not correspond to gravity of a ten pound vapor tension product. It should be borne in mind that each factor in this table represents only an approximation since gravity conversion factors are dependent upon the composition of the gasoline. It is, therefore, not advisable to use the factors in this table over a range greater than four degrees Baume (plus or minus two degrees Baume):

Factors Affecting Results of Tests of Gas by the Charcoal Testing Method—A careful study has been made of the following factors: Rate of gas flow; Saturation of absorbent with gasoline; Temperature; Pressure; Amount of moisture present in the charcoal and in the gas to be tested.

It has been shown that rates up to 60 cu. ft. per hour may be used on lean gas without materially affecting the results of tests with this apparatus. In no case should the rate of gas flow be so great that the test is completed in less than about twenty minutes. This affords opportunity for dissipation of heat caused by absorption of gasoline and increases chances of obtaining a representative sample of the gas for the test.

The saturation of the absorbent with gasoline may vary from 3 per cent by volume (7.5 cc. of distillate) to 15 per cent (37.5 cc. of distillate) without materially affecting results of tests, providing precautions regarding methods of testing as described in this article, are carefully followed. The results of tests by the writer in which distillates of 8.0;

16.0; 20.0; 28.0; 32.0 and 38.0 cc. were obtained, showed a maximum variation from the mean value of only 6 per cent and an average variation from the mean value of only 3.8 per cent. The limits of saturation of charcoal with gasoline depend to some extent upon the quality and quantity of gasoline fractions present in the gaseous mixture.

Pressure has but little effect upon the absorption of gasoline by charcoal. Absorption tests by this apparatus are carried out at atmospheric pressure. The accuracy of the method would not be materially increased by attempting to conduct tests at higher pressures.

Experiments have shown that, with other conditions of experiment constant, the amount of gasoline absorbed by charcoal depends upon the temperature of the absorbent. The lower the temperature the greater is the amount and the higher is the gravity of gasoline absorbed by the charcoal. Since the condensate is generally weathered to 60 deg. fahr. or to a product having a desired vapor tension, and the yield calculated on the volume of the weathered product, the temperature has little effect upon results of tests, as far as practical testing purposes are concerned. It has been shown that charcoal will absorb gasoline until a temperature of 600 deg. fahr. has been reached, the temperature curve being a straight line. The amount of gasoline absorbed by charcoal at temperatures above 550 deg. fahr. is practically nil.

The percentage of water that may be present in the charcoal without appreciably affecting its value as an absorbent for gasoline vapors depends upon several factors, chief of which are the quality of the charcoal, temperature, and the moisture content and the gasoline content of the gas. It has been shown that charcoal of approved quality may contain at least 4 per cent moisture content without unduly impairing the value of the absorbent for use in tests of gas for gasoline content. During tests of very rich gas, the heat caused

by absorption of vapors will sometimes remove a large amount of water from charcoal having a high moisture content.

If the gas tested has a very high moisture content, the absorption capacity of the charcoal for the more volatile vapors will be reduced. The gasoline extracted in such cases will be more stable than is generally obtained. If desired, the gas may be dried by first passing it through a tube of granular anhydrous calcium chloride.

Applicability of the Method and Apparatus to Other Industries--Actual tests have shown that the apparatus and method is applicable for determining the amount of other vapors present in other gaseous mixtures. It has been used in testing such mixtures as enriched water gas for condensable hydrocarbons, gases evolved from oil cracking stills for gasoline content, benzol and toluol air mixtures, alcohol air mixtures, gasoline air mixtures, acetone air mixtures, ether air mixtures, chloroform air mixtures and amyl acetate air mixtures. The distillation method requires modification in some cases.

Table 47

RESULTS OF SOME COMPARATIVE TESTS WITH THE CHARCOAL AND OIL ABSORPTION METHODS

Sample No.	Method	Type of oil Absorber	Yield G.P.M.	Gasoline recovered deg. B.
1	Charcoal	.....	0.22	90.4
1	Oil	1 Coil	0.20	90.2
2	Charcoal	.....	1.21	84.0
2	Oil	1 Coil	1.07	83.0
3	Charcoal	.....	2.35	86.0
3	Oil	1 Coil	2.15	85.0
4	Charcoal	.....	2.04	89.0
4	Oil	1 Coil	1.74	87.0
5	Charcoal	.....	4.18	90.8
5	Oil	4 Coils B of M.	4.08	91.0

Comparative Tests of Charcoal Apparatus with Portable Absorbers—A large number of comparative tests have been made with the charcoal and oil absorption methods. The results of a few of these tests are presented in Table 47. In every case, the charcoal absorption method shows a higher yield than does the oil absorption method. The four coil type of absorber designed by W. P. Dykema of the U. S. Bureau of Mines, gives results that check very closely with the charcoal testing method, providing corrections are made for gas volume shrinkage through the absorber.

The single coil type of absorber and the four coil type of absorber designed by W. P. Dykema of the Bureau of Mines fail to completely extract the gasoline from the gas. This has been shown by tests made on the outlet gas of the absorbers when operated at proper rates and amounts of gas flow, as prescribed in Bureau of Mines Publications. Although there is gasoline present in the outlet gas from the four coil type of absorber, the results show that the amount is small.

Table 48

RESULTS OF COMPARATIVE TESTS WITH PORTABLE COMPRESSION OUTFITS AND THE CHARCOAL METHOD

Sample No.	Method	Yield G. P. M.	Gasoline Recovered Deg. B.
1	Charcoal	5.17	91.6
1	Test Car No. 1	4.52	90.8
2	Charcoal	1.67	84.0
2	Test Car No. 3	1.42	82.0
3	Charcoal	8.54	88.7
3	Test Car No. 3	8.35	89.0
4	Charcoal	2.00	85.7
4	Test Car No. 3	1.63	85.8
5	Charcoal	1.03	85.7
5	Test Car No. 1	0.80	84.0

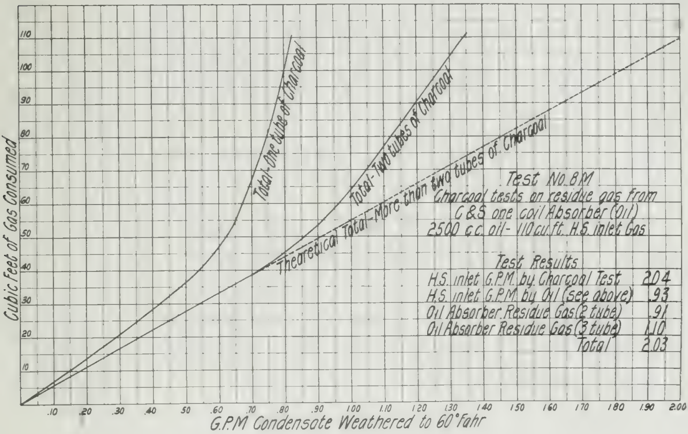


Fig. 42

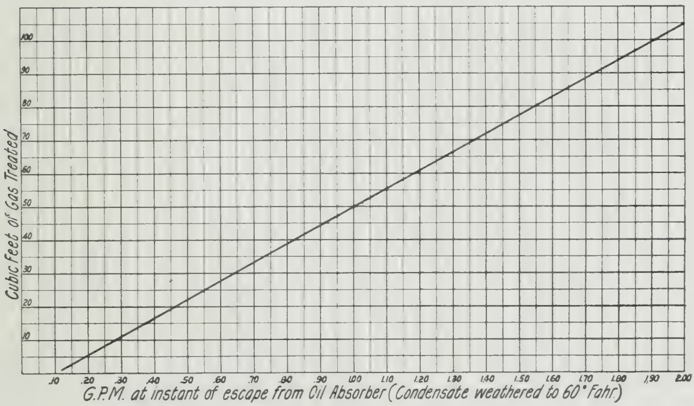


Fig. 43

Comparative Tests with Portable Compressor Outfits (Physical Testers) with Charcoal Apparatus—A large number of comparative tests with the small portable compressor outfit and the charcoal method have been made. The results of tests by the charcoal method, after weathering the

condensate to 60 deg. fahr. are generally higher than those obtained by the compressor outfit. The percentage difference between results of tests by the two methods becomes less as the gasoline content of the gas increases, and check very closely on gases showing more than about 3.0 G. P. M.

Results of Tests Compared with Plant Practice—Numerous tests have been made at oil absorption plants and at compression plants. Wherever accurate data could be obtained for the amount of gas handled by the plant and for the amount of gasoline sold, the results of tests by the charcoal method checked plant production very closely. As a rule, a plant that leaves a large amount of gasoline in the residue gas shows a lower gasoline production than should be expected, judging from results of tests by the charcoal method. On the other hand, a plant that is operating very efficiently generally shows a trifle greater production than would be expected judging from results of tests by the charcoal method. This latter case is especially true of plants which operate at very low temperatures, and which make use of a large quantity of blending material.

There are a number of ways in which a figure for the percentage efficiency of gasoline plants can be calculated, but the gasoline in the outlet gas (G. P. M.) forms a better gauge of the satisfactory operation of a plant than any percentage of efficiency. The gasoline content of the gas at many plants varies considerably from day to day, so that an average figure is sometimes very hard to obtain, unless a very large number of tests are made over a long period of time. This is due to several factors, some of which are the variations in pressure on the wells and the shutting in and opening different wells.

The Charcoal Testing Method does not give, neither does any other direct testing method give the maximum salable products obtainable by plants operating at very high

efficiencies, especially plants which make use of large quantities of blending material. Such plants are able to sell a certain amount of dissolved gas which will not liquefy in the condenser of the charcoal testing apparatus; in other words, while the charcoal testing apparatus is more efficient than any plant in removing gasoline from natural gas, it is less efficient than some plants in recovering the gasoline which it has extracted. Some plants operating at very high efficiency really have methods of making a mixture of gasoline and dissolved gas and not gasoline in the true sense of the word.

There follows the results of a few tests made of the inlet and outlet gases of gasoline plants:

Table 49

RESULTS OF TESTS OF GASES AT GASOLINE PLANTS

Kind of Plant	Plant No.	Method	Yield G.P.M. (Inlet)	Gasoline Produced deg. B.	Yield G.P.M. (Outlet)
...	1	Char.	.175	88.0	.057
Abs.	1	Plant	.121	86.0	....
....	2	Char.	.516	88.0	.103
Abs.	2	Plant	.381	90.5	....
....	3	Char.	.234	88.0	.034
Abs.	3	Plant	.268	90.0	....
....	4	Char.	1.33	88.0	.15
Comp.	4	Plant	1.40	90.0	....
....	5	Char.	1.83	88.0	0.57
Comp.	5	Plant	1.42	84.0	....
....	6	Char.	2.38	98.0	0.59
Comp.	6	Plant	1.83	100.0	....

Results of Tests of Gas from Gas and Oil Wells—In order to show how closely the results of individual tests check each other and to afford some idea of the extensive use to which the charcoal testing method has been subjected, the results of a few representative tests of gas from different localities are presented in the following table:

Table 50

RESULTS OF TESTS OF GAS FROM SEVERAL LOCALITIES

	A	B	C	D	E	F	G	H
Sample No. 1	0.42	1.96	1.09	1.75	0.31	1.06	5.00	1.76
" " 1	0.38	2.04	....	....	....	....	5.42	1.77
" " 2	0.63	2.03	1.01	1.59	0.28	1.89	4.87	1.36
" " 2	0.58	2.06	1.04	1.79	0.27	....	4.93	1.31
" " 2	0.56	....	....	....	....	....	4.63	1.31
" " 3	0 22	1.98	1.16	3.57	1.36	1.96	1.50	....
" " 3	0.20	2.10	1.11	3.60	....	....	1.30	....
" " 3	0.23	....	....	....	....	....	....	....
" " 4	0.24	1.67	1.41	2.25	1.06	2.33	1.48	....
" " 4	0.24	1.76	1.39	2.23	....	2.43	1.49	....
" " 4	0.26	....	....	....	....	....	1.52	....
" " 5	0.25	1.91	0.88	....	1.09	....	1.49	....
" " 5	0.24	1.86	1.01	....	....	....	1.47	....
" " 5	0.21	....	....	....	....	....	....	....
" " 6	0.28	2.10	1.23	....	0.66	....	....	....
" " 6	0.26	2.04	1.25	....	....	....	....	....
" " 6	0.27	....	....	....	....	....	....	....
" " 7	1.16	1.75	0.83	....	0.42	....	....	....
" " 7	1.21	1.93	0.76	....	....	....	....	....
" " 7	1.16	....	....	....	....	....	....	....
" " 8	0.31	2.00	0.85	....	1.09	....	....	....
" " 8	0.31	1.91	1.01	....	....	....	....	....
" " 8	0.34	....	....	....	....	....	....	....
" " 9	0.88	1.84	1.29	....	0.32	....	....	....
" " 9	0.86	1.72	1.34	....	....	....	....	....
" " 10	0.44	2.25	1.10	....	1.17	....	....	....
" " 10	0.43	2.27	1.10	....	....	....	....	....
" " 11	1.18	1.93	0.57	....	2.25	....	....	....
" " 11	1.25	1.96	0.57	....	....	....	....	....
" " 12	0.77	2.10	1.86	....	1.45	....	....	....
" " 12	0.82	2.17	1.86	....	....	....	....	....
" " 13	1.11	2.28	0.86	....	1.78	....	....	....
" " 13	1.13	2.18	0.87	....	....	....	....	....
" " 14	....	2.37	0.77	....	1.04	....	....	....
" " 14	....	2.33	0.82	....	....	....	....	....
" " 15	....	....	0.40*	....	0.74	....	....	....
" " 15	....	....	0.38*	....	....	....	....	....
" " 16	....	....	0.36*	....	1.95	....	....	....
" " 16	....	....	0.36*	....	2.10	....	....	....
" " 17	....	....	0.25*	....	1.40	....	....	....
" " 17	....	....	0.23*	....	....	....	....	....
" " 18	....	....	0.11*	....	1.38	....	....	....
" " 18	....	....	0.11*	....	....	....	....	....

A: Duke Field, Desdemona, Texas, October, 1919. Yield in Gallons per M. cu. ft. of 88 deg. B. Product.

B: Lee County, Kentucky, Big Sinking Pool, December, 1919. Yield in Gallons per M. cu. ft. of 86 deg. B. Product of 9½ lb. Vapor tension at 100 deg. fahr.

C: Casinghead Gas near Washington, Pennsylvania, March, 1919. Yield in Gallons per M. cu. ft. of condensate of 82-90 deg. B. *Natural Gas near Washington, Pennsylvania.

D: Tepetate, Los Naranjos, and Casiano Gas, July, 1919. Yield in Gallons per M. cu. ft. of 84 deg. B. gasoline of Approximately 10 lb. Vapor Tension at 100 deg. fahr.

E: Roane County, West Virgina, Casinghead Gas, February, 1919. Yield in galllons per M. cu. ft. of condensate of 82-86 deg. B.

F: Casinghead Gas near Bolivar, New York, September, 1919. Yield in Gallons per M. cu. ft. at Approximately 94 deg. B. product.

G: Casinghead Gas, in Oklahoma, 1920. Yield in Gallons per M. cu. ft. of condensate weathered to 60 deg. fahr.

H: Casinghead Gasoline, California, August, 1919. Yield in Gallons per M. cu. ft. of 79 deg. B. of 10 lb. vapor tension at 100 deg. fahr.

Table 51—FACTORS FOR GASOLINE ABSORPTION

Ft.	Number	Ft.	Number	Ft.	Number	Ft.	Number	Ft.	Number	Ft.	Number
1	264.2706	51	5.1817	101	2.6165	151	1.7501	201	1.3148	251	1.0528
2	132.1352	52	5.0821	102	2.5908	152	1.7386	202	1.3082	252	1.0487
3	88.0902	53	4.9862	103	2.5657	153	1.7272	203	1.3010	253	1.0445
4	66.0676	54	4.8939	104	2.5410	154	1.7160	204	1.2954	254	1.0404
5	52.8541	55	4.8049	105	2.5168	155	1.7049	205	1.2891	255	1.0364
6	44.0451	56	4.7191	106	2.4931	156	1.6940	206	1.2828	256	1.0323
7	37.7529	57	4.6363	107	2.4698	157	1.6832	207	1.2767	257	1.0283
8	33.0338	58	4.5564	108	2.4469	158	1.6726	208	1.2705	258	1.0243
9	29.3634	59	4.4792	109	2.4245	159	1.6621	209	1.2644	259	1.0203
10	26.4270	60	4.4045	110	2.4025	160	1.6516	210	1.2584	260	1.0164
11	24.0246	61	4.3323	111	2.3808	161	1.6414	211	1.2525	261	1.0125
12	22.0225	62	4.2624	112	2.3595	162	1.6313	212	1.2465	262	1.0086
13	20.3285	63	4.1948	113	2.3386	163	1.6213	213	1.2407	263	1.0048
14	18.8764	64	4.1292	114	2.3181	164	1.6114	214	1.2349	264	1.0010
15	17.6180	65	4.0657	115	2.2980	165	1.6016	215	1.2292	265	.9972
16	16.5169	66	4.0041	116	2.2782	166	1.5920	216	1.2234	266	.9935
17	15.5453	67	3.9443	117	2.2587	167	1.5825	217	1.2178	267	.9898
18	14.6817	68	3.8863	118	2.2396	168	1.5730	218	1.2122	268	.9860
19	13.9089	69	3.8300	119	2.2208	169	1.5657	219	1.2067	269	.9824
20	13.2135	70	3.7753	120	2.2022	170	1.5545	220	1.2012	270	.9788
21	12.5843	71	3.7221	121	2.1840	171	1.5454	221	1.1958	271	.9752
22	12.0123	72	3.6704	122	2.1661	172	1.5364	222	1.1904	272	.9713
23	11.4900	73	3.6201	123	2.1485	173	1.5276	223	1.1851	273	.9680
24	11.0112	74	3.5712	124	2.1312	174	1.5188	224	1.1797	274	.9643
25	10.5708	75	3.5236	125	2.1142	175	1.5101	225	1.1745	275	.9610
26	10.1642	76	3.4772	126	2.0974	176	1.5015	226	1.1693	276	.9575
27	9.7878	77	3.4321	127	2.0809	177	1.4931	227	1.1642	277	.9540
28	9.4382	78	3.3881	128	2.0646	178	1.4846	228	1.1590	278	.9506
29	9.1128	79	3.3452	129	2.0486	179	1.4764	229	1.1540	279	.9472
30	8.8090	80	3.3033	130	2.0328	180	1.4681	230	1.1490	280	.9438
31	8.5248	81	3.2626	131	2.0173	181	1.4601	231	1.1440	281	.9405
32	8.2584	82	3.2228	132	2.0020	182	1.4520	232	1.1391	282	.9371
33	8.0082	83	3.1840	133	1.9870	183	1.4441	233	1.1342	283	.9338
34	7.7726	84	3.1460	134	1.9721	184	1.4362	234	1.1293	284	.9305
35	7.5506	85	3.1091	135	1.9576	185	1.4285	235	1.1246	285	.9273
36	7.3508	86	3.0729	136	1.9431	186	1.4208	236	1.1198	286	.9240
37	7.1424	87	3.0376	137	1.9290	187	1.4132	237	1.1151	287	.9208
38	6.9544	88	3.0030	138	1.9150	188	1.4057	238	1.1104	288	.9176
39	6.7762	89	2.9693	139	1.9012	189	1.3983	239	1.1057	289	.9144
40	6.6067	90	2.9363	140	1.8876	190	1.3909	240	1.1011	290	.9113
41	6.4456	91	2.9041	141	1.8743	191	1.3836	241	1.0966	291	.9081
42	6.2921	92	2.8725	142	1.8610	192	1.3764	242	1.0920	292	.9050
43	6.1458	93	2.8416	143	1.8480	193	1.3693	243	1.0875	293	.9019
44	6.0061	94	2.8114	144	1.8352	194	1.3622	244	1.0831	294	.8989
45	5.8727	95	2.7818	145	1.8226	195	1.3552	245	1.0787	295	.8958
46	5.7450	96	2.7528	146	1.8100	196	1.3483	246	1.0742	296	.8928
47	5.6228	97	2.7244	147	1.7976	197	1.3415	247	1.0699	297	.8898
48	5.5058	98	2.6966	148	1.7856	198	1.3347	248	1.0650	298	.8868
49	5.3933	99	2.6694	149	1.7736	199	1.3280	249	1.0613	299	.8838
50	5.2854	100	2.6427	150	1.7618	200	1.3213	250	1.0571	300	.8809

PART EIGHT

Gathering Lines.

VACUUM, PIPE LINES, BOOSTER STATION, PIPE LINE CAPACITIES.

VACUUM

Throughout this book the word vacuum will be used in place of the expression "minus pressure or 'vacuum.'" A perfect vacuum has never been obtained and probably never will be. The true meaning of the word vacuum is—a void; a vacuity, a space where no material substance exists.

The meaning intended and understood by the casing-head gas fraternity is that of a partial vacuum or any minus pressure below atmospheric pressure. It is in that sense that the word vacuum is used in this book.

Placing a Vacuum on Wells—In some instances where the oil sand is very "loose" or coarse, placing a high vacuum suddenly on a well has reduced the production of oil. This caused a sudden inrush of oil and gas carrying sand with it, which partially filled up the hole and interfered with the production of oil.

A light vacuum should be placed on wells first and gradually increased until the desired vacuum is obtained. By so doing the vacuum effect has opportunity to gradually work back into the sand without causing any sudden inrush of oil and gas which would carry sand, heavy oil, etc. with them.

Advantage of Pumping Gas from a Well Under a Vaccum—It is a well known fact that the lower the pressure on a liquid the lower the boiling point, and the higher the pressure the higher the boiling point. It is just as essential to compress casinghead gas to a high pressure to condense the gasoline vapors, as it is to lower the pressure on the well

to lower the boiling point and increase the evaporation of the gasoline in the oil lying in the natural state in the oil sand. For example: Water will boil at 212 deg. fahr. at sea level or an atmospheric pressure of 14.7 lb. per sq. inch. Water in a boiler under pressure of 15 lb. per sq. inch above atmospheric pressure will boil at a temperature of 249 deg. fahr. and under a pressure of thirty pounds above atmospheric pressure will boil at a temperature of 273 deg. fahr. Likewise when the pressure is lowered to below atmospheric pressure the boiling point of water drops below 212 deg. fahr. At a pressure equal to 29.1 inches of mercury vacuum the water will boil at 32 deg. fahr.

The same theory applies to all liquid hydrocarbons. Therefore it is good practice to apply as great a vacuum as possible on a casinghead gas well, as it increases both the flow of the oil and the flow of the gas.

PIPE LINES

The lines are seldom very long or very large in diameter. Most of the lines in use are from two inch to eight inch.

As the pressure is often many inches of mercury below atmospheric pressure, and the gas volumes to be carried are generally small, considerably larger lines are required than if the same volume of gas were to be carried at a pressure higher than atmospheric. Pipe lines should be large thereby decreasing the loss in pressure between the vacuum pumps and the wells, and increasing the vacuum in the wells as there is less friction in large lines.

While plain end pipe is occasionally used to transport casinghead gas, screw pipe is in more common use. Free gasoline on the rubber rings used on plain end pipe, quickly rots the rubber and creates leaks. With the screw joint, the gasoline has a tendency to cut the asphaltum paint used on the thread and this creates small leaks.

When screw pipe is used, thick shellac is better to use

on the pipe threads than asphaltum. In addition it is good policy to use collar leak clamps on every joint.

With welded pipe joints, all liability of leaks is eliminated. The reader will appreciate that deposited gasoline, which is always found in casinghead gas pipe lines, is a very difficult liquid to control, consequently the advantage which the welded joint has over the plain end and screwed joints should bring it into general use.

Ditching—The size of the ditches for different sizes of gas lines is as follows:

Table 52—DITCH DIMENSIONS

Size of Pipe	Depth in Inches	Width in Inches
3- and 4-inch	20	Shovel
6-inch	24	Width
8-inch	28	20
10-inch	30	22
12-inch	32	24
16-inch	36	26

Welded Pipe Lines*—Oxy-acetylene welded pipe lines are quite common in the gas fields. Although the pipe lines are not required to stand a very high pressure in the casinghead gas business, except when used at the plant, the joints must be securely welded on account of the contraction and expansion of the pipe. Unless expansion sleeves are used, the pipe lines should be laid in a wavy line to allow for contraction. Should these sleeves be used it is best to pack them with paronite instead of rubber, as gasoline has a very deteriorating effect on the rubber packing, resulting in leakage.

When welded lines are to be installed to carry a high pressure, such as on the discharge side of the high pressure compressor, where the gas is subject to the pulsation of the

* A complete and detailed article on Welded Pipe Line will be found in the Third Edition of the "Hand Book of Natural Gas," by the author.

Table 53—CASING SIZES

Nominal Inside Diameter Inches	Outside Diameter Inches	Nominal Weight per Foot Pounds	Number of Threads per Inch	Outside Diameter of Couplings Inches
2	$2\frac{1}{4}$	2.16	14	2.687
$2\frac{1}{4}$	$2\frac{1}{2}$	2.75	14	2.875
$2\frac{1}{2}$	$2\frac{3}{4}$	3.04	14	3.187
$2\frac{3}{4}$	3	3.33	14	3.500
3	$3\frac{1}{4}$	3.96	14	3.781
$3\frac{1}{4}$	$3\frac{1}{2}$	4.28	14	4.000
$3\frac{1}{2}$	$3\frac{3}{4}$	4.60	14	4.250
$3\frac{3}{4}$	4	5.47	14	4.625
4	$4\frac{1}{4}$	5.85	14	4.687
$4\frac{1}{4}$	$4\frac{1}{2}$	6.00	14	4.937
$4\frac{1}{4}$	$4\frac{1}{2}$	9.00	14	4.937
$4\frac{1}{2}$	$4\frac{3}{4}$	6.55	14	5.218
$4\frac{1}{2}$	$4\frac{3}{4}$	9.00	14	5.218
$4\frac{3}{4}$	5	7.58	14	5.562
5	$5\frac{1}{4}$	8.00	14	5.781
5	$5\frac{1}{4}$	10.00	14	5.781
5	$5\frac{1}{4}$	13.00	$11\frac{1}{2}$	5.781
5	$5\frac{1}{4}$	17.00	$11\frac{1}{2}$	5.781
$5\frac{3}{16}$	$5\frac{1}{2}$	8.40	14	6.062
$5\frac{3}{16}$	$5\frac{1}{2}$	13.00	$11\frac{1}{2}$	6.062
$5\frac{5}{8}$	6	10.16	14	6.062
$5\frac{5}{8}$	6	12.00	$11\frac{1}{2}$	6.625
$5\frac{5}{8}$	6	14.00	$11\frac{1}{2}$	6.625
$5\frac{5}{8}$	6	17.00	$11\frac{1}{2}$	6.625
$6\frac{1}{4}$	$6\frac{5}{8}$	11.50	14	7.125
$6\frac{1}{4}$	$6\frac{5}{8}$	13.00	$11\frac{1}{2}$	7.125
$6\frac{1}{4}$	$6\frac{5}{8}$	17.00	$11\frac{1}{2}$	7.125
$6\frac{5}{8}$	7	12.45	14	7.687
$6\frac{5}{8}$	7	17.00	10	7.687
$7\frac{1}{4}$	$7\frac{5}{8}$	13.50	14	8.220
$7\frac{5}{8}$	8	15.00	$11\frac{1}{2}$	8.625
$7\frac{5}{8}$	8	20.00	$11\frac{1}{2}$	8.625
$8\frac{1}{4}$	$8\frac{5}{8}$	16.00	$11\frac{1}{2}$	9.312
$8\frac{1}{4}$	$8\frac{5}{8}$	20.00	$11\frac{1}{2}$	9.312
$8\frac{1}{4}$	$8\frac{5}{8}$	24.00	8	9.312
$8\frac{5}{8}$	9	17.50	$11\frac{1}{2}$	9.750
$9\frac{5}{8}$	10	21.00	$11\frac{1}{2}$	10.812
$10\frac{5}{8}$	11	23.00	$11\frac{1}{2}$	......
$11\frac{5}{8}$	12	25.15	$11\frac{1}{2}$	......
$12\frac{1}{2}$	13	35.75	$11\frac{1}{2}$	......
$13\frac{1}{2}$	14	42.02	$11\frac{1}{2}$	......
$14\frac{1}{2}$	15	47.66	$11\frac{1}{2}$	......
$15\frac{1}{2}$	16	51.47	$11\frac{1}{2}$	......

piston, the "saw tooth" joint is the better to adopt in welding. It makes a much stronger joint than the butt welded one and is less liable to blow out while in service.

Pipe Line Losses—With many of the large gasoline plants, the gas is not only measured at the gas producing leases where it is purchased, but also through one or more large meters at the plant. If there was no condensation of gasoline from the casinghead gas in the pipe line between the leases and the plant, the lease meters and the plant meter should check within a very small percentage of one another.

Table 54—STANDARD LINE PIPE

Nominal Inside Diameter Inches	Actual Outside Diameter Inches	Nominal Thickness Inches	Nominal Weight per Foot Pounds	Number of Threads per Inch of Screw
2	2.375	.154	3.609	11½
2½	2.875	.204	5.739	8
3	3.5	.217	7.536	8
3½	4.	.226	9.001	8
4	4.5	.237	10.665	8
4½	5.	.246	12.49	8
5	5.563	.259	14.502	8
6	6.625	.28	18.762	8
7	7.625	.301	23.271	8
8	8.625	.281	25.00	8
8	8.625	.322	28.177	8
9	9.625	.344	33.701	8
10	10.75	.2865	32.00	8
10	10.75	.3145	35.00	8
10	10.75	.366	40.065	8
12	12.75	.340	45.00	8
12	12.75	.375	48.985	8

Nearly all field lines are equipped with drips which collect the gasoline condensed in the lines. This condensation is caused through changes in temperature, not only between day and night but also because a portion of the lines are exposed to the atmosphere while other portions are either covered or buried. The greatest amount of condensation

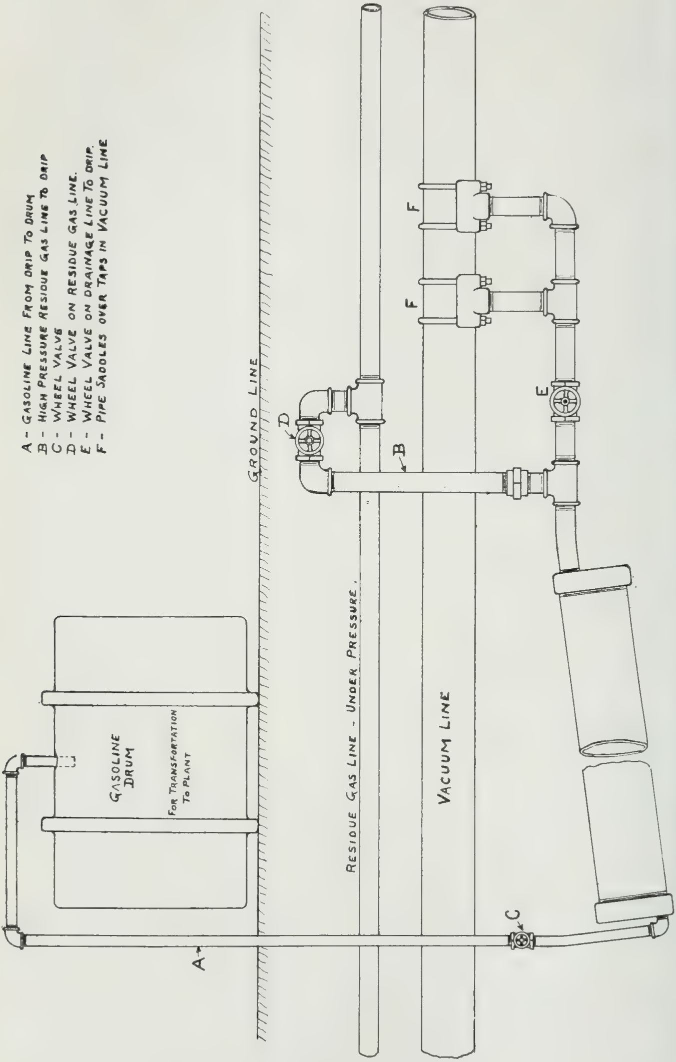


Fig. 44—GASOLINE DRIP WITH CONNECTION TO RESIDUE GASOLINE FOR BLOWING GASOLINE INTO DRUM

occurs in cold weather. The drips are pumped or "blown off" and the gasoline and light oils are saved for refining into gasoline.

When checking lease meters with a plant meter, due consideration must be given to drip accumulation. Between 32 to 42 gallons of gasoline will make 1,000 cubic feet of gasoline vapor or gas, the quantity varying with the quality of the gasoline.

Pipe Line Drips—Gathering lines should be laid with as few pockets as possible. The heavy hydrocarbons in casing-head gas are easily condensed in pipe lines due to the gas coming in contact with a cold section of the line. The pipe line temperatures vary according to their location above or below the surface and according to the temperatures of the ground and the atmosphere. It is very important to install drips along the lines, especially in low spots.

Accumulations from drips should be drawn off and refined. Often they are of a yellowish tint. This color comes from the oil in the well. If gasoline is found clear in color, it can be put into stock tanks but if it is off color, it must be refined. By distilling in a steam still, the same as employed at a refinery, the gasoline recovered will be of proper color and of good quality.

Fig. 44 shows a gasoline drip for a pipe line when the pressure of the gas is below the atmospheric pressure. If the pressure of the gas is above the atmosphere only one gate is necessary and it should be placed at the blow-off. To blow the drip when the pressure of the gas is below atmospheric pressure, close the gate nearest the pipe line and then open the "blow-off" gate. After the drip is drained, close the "blow-off" gate and open the gate next to the pipe line.

Invariably the residue gas line is laid parallel to the gathering line. This permits connecting it with inlet to the drip, on the gathering or vacuum line, to blow the gasoline from the drip into a drum, as shown in Fig. 44.

In using this method, valve E must be closed first before opening valve D or C. When gas in the gathering line is above atmoshperic pressure, no connection need be made with the residue line.

Table 55

STANDARD WROUGHT IRON PIPE FOR STEAM, GAS, OIL OR WATER

Diameters, Inches			Thickness of Pipe Inch	Outside Diameter of Coup'gs Inches	Feet of Pipe for 1 Cu.Ft. Volume	Weight of Pipe per Ft. Pounds	No. of Threads per Inch
Nom. Inside	Actual Inside	Actual Outside					
1/8	.270	.405	.068	.510	2500.	.243	27
1/4	.364	.54	.086	.720	1385.	.422	18
3/8	.494	.675	.091	.844	751.5	.561	18
1/2	.623	.84	.109	1.156	472.4	.845	14
3/4	.824	1.05	.113	1.375	270.	1.126	14
1	1.048	1.315	.134	1.625	166.9	1.670	11½
1¼	1.380	1.66	.140	2.125	96.25	2.258	11½
1½	1.611	1.9	.145	2.375	70.65	2.694	11½
2	2.067	2.375	.154	2.937	42.36	3.667	11½
2½	2.468	2.875	.204	3.500	30.11	5.773	8
3	3.067	3.5	.217	4.062	19.49	7.547	8
3½	3.548	4.	.226	4.687	14.56	9.055	8
4	4.026	4.5	.237	5.187	11.31	10.728	6
4½	4.508	5.	.247	5.750	9.03	12.492	8
5	5.045	5.563	.259	6.343	7.20	14.564	8
6	6.065	6.625	.280	7.343	4.98	18.767	8
7	7.023	7.625	.301	8.437	3.72	23.410	8
8	7.982	8.625	.322	9.375	2.88	28.348	8
9	9.001	9.688	.344	10.560	2.26	34.077	8
10	10.019	10.75	.366	11.680	1.80	40.641	8
12	12.000	12.75	.375	13.930	1.27	49.000	8

A drip should be placed at all low spots in the line. The length of the drip is dependent upon the amount of gasoline that is condensed in the line, and can be made up of several joints of pipe instead of one. Extra long drips can be placed on small sized lines, if desired.

BOOSTER STATION

A booster station generally refers to a building near a group of casinghead gas wells in which is installed a vacuum pump and a booster or compressor. The power is generally furnished by a gas engine for each compressor.

The vacuum pump is built with large size cylinders and is run at low speed. It is connected directly on the gas lines from the casinghead gas wells.

The object is to pump or create a vacuum on the lines and wells and to deliver a large volume of gas at approximately atmospheric pressure to the booster or compressor adjoining it.

The booster or compressor receives the gas from the vacuum pump at about atmospheric pressure and raises the pressure from 25 to 40 lb. to overcome the friction in the pipe line between the booster station and the main plant.

Fig. 45—USING A PORTABLE TELEPHONE ALONG PIPE LINE

Large tanks with baffle plates on the interior are installed on the discharge side of the vacuum pump and the booster or compressor. Considerable gasoline of low gravity is collected in them. This gasoline is placed in drums and hauled to the main plant. If the color is good it is put into a stock tank, but if it is colored, i. e., yellow, it is refined in a steam still similar to the method employed at refineries.

PIPE LINE CAPACITIES

Flow of Natural Gas in Pipe Lines*—

Formula—$Q = 32.5a.\sqrt{\frac{P_1^2 - P_2^2}{L}}$

Q = cubic feet per hour.

32.5 = constant for gas of a specific gravity of 1.0.

a = Coefficient dependent upon diameter of pipe.

L = length of line in miles.

P_1 = gauge pressure + 14.4 pounds at intake end of line.

If the gas is under a vacuum, P_1 = inches of mercury vacuum expressed as the absolute pressure in pounds per square inch. See Table 58.

P_2 = gauge pressure + 14.4 pounds at discharge end of line.

If the gas is under a vacuum, P_2 = inches of mercury vacuum expressed as the absolute pressure in pounds per square inch. See Table 58.

Do not use inches of mercury for the value of P_1 and P_2. Reduce the inches of mercury vacuum to lb. per square inch, absolute pressure. One inch of mercury equals .4908 lb. See table on following page.

All pipe line capacity tables on pages 198 to 201 are based on the foregoing formula.

Table 56—FACTORS FOR PIPE DIAMETER

Value of (a)

Pipe Diam.	Multi-plier	Pipe Diam.	Multi-plier	Pipe Diam.	Multi-plier	Pipe Diam.	Multi-plier
¼″	0.0317	2½″	10.37	8″	198	20″b	1860
½″	0.1810	3″	16.50	10″	350	20″c	2055
¾″	0.5012	4″	34.10	12″	556	24″c	3285
1″	1.0000	5″	60.00	15″b	863	30″c	5830
1½″	2.9300	5⅝″	81.00	16″b	1025	36″c	9330
2″	5.9200	6″	95.00	18″b	1410		

NOTE *b*—For pipe greater than 12 inches in diameter the measurement is made on the outside. The multipliers for these pipes are based on the inside diameter being ¾ inch less than the outside. *c*—Inside diameters of cast-iron or riveted pipe.

* By F. H. Oliphant in "Production of Natural Gas in 1900" United States Geological Survey.

The tables of capacities of various size pipe lines on pages 198 to 201 give the capacities based on a specific gravity of 1.0. When it is desired to determine a pipe line capacity at any other specific gravity, multiply the capacity given in tables by the multiplier opposite the correct specific gravity as found in the table below.

These factors or multipliers are equal to $\sqrt{\dfrac{1.0}{\text{Sp.Gr. Gas.}}}$

Table 57—SPECIFIC GRAVITY FACTORS

For Tables Pages 198 to 201

Specific Gravity	Multiplier	Specific Gravity	Multiplier	Specific Gravity	Multiplier
0.60	1.29099	.90	1.05409	1.20	0.91287
0.65	1.24034	.95	1.02597	1.30	0.87705
0.70	1.19522	1.00	1.00000	1.40	0.84515
0.75	1.15470	1.05	0.97589	1.50	0.81649
0.80	1.11803	1.10	0.95346	1.60	0.79056
0.85	1.08465	1.15	0.93250	1.70	0.76696

Correction for temperature, add 1 per cent for each 10 degrees below 60 deg. fahr., and subtract 1 per cent for each 10 degrees above 60 deg. fahr.

Table 58

MERCURY VACUUM—ABSOLUTE PRESSURE

Atmospheric Pressure 14.4

Inches Mercury Vacuum	Abs. Press. Pounds per sq. in.	Inches Mer. Vacuum	Abs. Press. Pounds per sq. in.	Inches Mer. Vacuum	Abs. Press. Pounds per sq. in.
0	14.400	10	9.492	20	4.584
1	13.909	11	9.001	21	4.093
2	13.418	12	8.510	22	3.602
3	12.928	13	8.020	23	3.112
4	12.437	14	7.529	24	2.621
5	11.946	15	7.038	25	2.130
6	11.455	16	6.547	26	1.639
7	10.964	17	6.056	27	1.148
8	10.474	18	5.566	28	0.658
9	9.983	19	5.075	29	0.167

Table 59—PIPE LINE CAPACITIES

Quantity expressed in thousands of Cubic Feet per 24 hours
Atmospheric Pressure 14.4 Temperature 60 deg. fahr Specific Gravity 1.00
For Specific Gravity Factors see page 197

Length of Pipe Line in Miles	Intake Press. 20″ Vacuum		Intake Press. 15″ Vacuum		Intake Press. 10″ Vacuum		Intake Press. 5″ Vacuum			Length of Pipe Line in Miles
	Disch. Press.		Disch. Press.		Disch. Press.		Disch. Press.			
	28″ Vac.	25″ Vac.	25″ Vac.	20″ Vac.	25″ Vac.	15″ Vac.	25″ Vac.	15″ Vac.	10″ Vac.	
2 Inch Pipe Line										
¼	42	37	61	49	84	59	109	89	67	¼
½	30	26	43	35	60	41	77	63	47	½
1	21	18	30	24	42	29	54	44	33	1
2	15	13	21	17	30	20	38	31	23	2
3	11	10	17	14	24	17	31	25	19	3
2½ Inch Pipe Line										
½	52	46	77	61	106	73	134	110	83	½
1	37	33	54	43	75	51	95	78	59	1
2	26	23	38	31	53	36	67	55	41	2
3	21	19	31	25	43	30	55	45	34	3
4	18	16	27	21	37	26	48	39	29	4
3 Inch Pipe Line										
½	82	73	122	96	168	116	213	176	131	½
1	58	52	86	68	110	82	150	124	93	1
2	41	36	61	48	84	58	106	88	65	2
3	34	30	49	39	68	47	87	71	54	3
4	29	26	43	34	59	41	75	61	46	4
4 Inch Pipe Line										
½	170	152	252	201	347	239	442	363	273	½
1	120	107	177	142	246	169	311	256	192	1
2	85	76	126	100	173	119	221	181	136	2
3	70	62	102	81	142	97	180	148	111	3
4	60	53	89	71	122	84	156	128	96	4
6	49	44	73	58	100	69	128	105	78	6
5 Inch Pipe Line										
½	300	269	444	354	612	421	779	639	481	½
1	212	190	314	250	433	298	550	452	340	1
2	150	134	222	177	356	211	389	320	240	2
3	122	110	181	144	250	172	318	261	196	3
4	106	85	157	125	216	149	275	226	170	4
6	87	78	128	102	177	121	225	185	139	6
6 Inch Pipe Line										
1	336	300	495	395	685	472	867	715	537	1
2	237	212	351	279	484	333	615	506	380	2
3	194	173	286	227	395	272	502	413	310	3
4	168	149	248	197	342	236	435	357	268	4
6	137	122	202	161	279	192	355	291	219	6
10	106	94	157	124	216	149	274	226	170	10
8 Inch Pipe Line										
1	699	625	1033	824	1428	983	1807	1491	1120	1
2	495	443	732	582	1010	695	1283	1054	792	2
3	404	361	597	474	824	568	1047	860	647	3
4	350	312	517	412	713	492	906	745	560	4
6	285	254	421	336	582	401	739	608	457	6
10	221	197	327	259	451	311	573	471	354	10

Table 60—PIPE LINE CAPACITIES

Quantity expressed in thousands of Cubic Feet per 24 hours
Atmospheric Pressure 14.4 Temperature 60 deg. fahr. Specific Gravity 1.00
For Specific Gravity Factors see page 197

Length of Pipe Line in Miles	Intake Pressure 0 Lb. per Sq. In. — Discharge Pressure				Intake Pressure 3 Lb. per Sq. In. — Discharge Pressure				Length of Pipe Line in Miles
	25″ Vac.	15″ Vac.	10″ Vac.	5″ Vac.	25″ Vac.	15″ Vac.	5″ Vac.	0 lb.	
2 Inch Pipe Line									
¼	133	116	99	74	159	147	116	89	¼
½	93	82	71	53	113	103	83	63	½
1	67	58	50	37	79	73	58	44	1
2	46	41	35	26	56	51	41	31	2
3	37	33	28	21	46	42	34	26	3
2½ Inch Pipe Line									
½	163	144	124	92	197	182	145	112	½
1	115	102	88	65	140	129	102	79	1
2	81	72	62	46	98	91	72	56	2
3	67	59	51	38	81	74	59	46	3
4	58	51	44	33	70	64	51	40	4
3 Inch Pipe Line									
½	259	228	197	146	314	289	230	178	½
1	187	161	139	103	222	205	162	125	1
2	129	114	98	73	157	144	115	89	2
3	105	93	80	59	128	118	93	72	3
4	91	80	69	51	111	102	81	62	4
4 Inch Pipe Line									
½	535	472	408	301	649	599	475	367	½
1	387	334	287	213	459	423	336	260	1
2	267	236	203	150	324	299	238	183	2
3	218	192	166	123	265	249	194	150	3
4	189	167	143	106	229	210	167	130	4
6	155	136	118	87	187	173	137	106	6
5 Inch Pipe Line									
½	943	831	718	532	1143	1054	837	647	½
1	666	588	507	376	808	745	592	457	1
2	471	416	359	266	572	527	419	324	2
3	384	339	293	217	466	430	342	264	3
4	333	294	254	188	404	373	296	229	4
6	272	240	207	154	330	304	242	187	6
6 Inch Pipe Line									
1	1080	931	802	595	1279	1119	937	723	1
2	746	658	567	423	904	834	663	510	2
3	609	537	463	344	738	623	543	417	3
4	527	465	400	297	639	589	469	362	4
6	430	380	327	243	552	481	383	295	6
10	333	294	253	188	404	373	296	229	10
8 Inch Pipe Line									
1	2252	1940	1672	1242	2666	2458	1954	1508	1
2	1555	1372	1182	878	1886	1738	1382	1066	2
3	1269	1120	965	717	1540	1419	1128	870	3
4	1099	970	836	620	1333	1229	976	754	4
6	897	792	682	506	1089	1003	797	616	6
10	695	613	528	392	843	777	617	476	10

Table 61—PIPE LINE CAPACITIES

Quantity expressed in thousands of Cubic Feet per 24 hours
Atmospheric Pressure 14.4 Temperature 60 deg. fahr. Specific Gravity 1.00
For Specific Gravity Factors see page 197

Length of Pipe Line in Miles	Intake Pressure 6 Lb. Per Sq. Inch — Discharge Pressure				Intake Pressure 10 Lb. Per Sq. Inch — Discharge Pressure				Length of Pipe Line in Miles
	25″ Vac.	10″ Vac.	0 Lb.	3 Lb.	25″ Vac.	0 Lb.	3 Lb.	6 Lb.	
2 Inch Pipe Line									
¼	187	167	133	98	225	182	157	124	¼
½	132	117	94	69	158	128	111	87	½
1	93	83	66	49	112	91	78	62	1
2	66	58	47	34	79	64	55	44	2
3	54	47	38	28	65	52	45	36	3
2½ Inch Pipe Line									
½	231	206	165	122	278	225	195	153	½
1	164	146	117	86	197	160	138	108	1
2	116	103	83	61	139	113	98	76	2
3	95	84	67	50	113	92	80	62	3
4	82	73	58	43	98	80	69	54	4
3 Inch Pipe Line									
½	369	329	263	192	442	358	311	243	½
1	261	232	185	136	312	253	220	172	1
2	184	164	131	96	221	179	155	122	2
3	150	133	107	78	180	146	126	99	3
4	130	116	92	68	156	126	109	73	4
4 Inch Pipe Line									
½	762	679	543	400	913	741	643	503	½
1	539	480	384	283	646	523	455	356	1
2	381	339	271	200	456	370	321	252	2
3	311	277	220	163	373	302	263	206	3
4	269	239	191	141	323	262	227	178	4
6	220	196	157	116	264	214	186	145	6
5 Inch Pipe Line									
½	1342	1196	957	705	1609	1304	1132	886	½
1	949	845	676	498	1137	922	800	626	1
2	671	598	478	353	804	652	566	443	2
3	548	488	390	288	656	532	462	361	3
4	474	423	338	249	569	461	400	313	4
6	387	345	276	203	464	376	327	256	6
6 Inch Pipe Line									
1	1503	1338	1071	789	1801	1459	1267	991	1
2	1062	946	756	558	1273	1032	896	701	2
3	867	772	618	455	1039	842	732	574	3
4	751	669	535	394	900	729	633	496	4
6	613	546	437	371	735	595	517	405	6
10	475	423	339	249	569	461	400	313	10
8 Inch Pipe Line									
1	3132	2789	2232	1644	3753	3042	2432	2066	1
2	2215	1972	1578	1163	2653	2151	1868	1461	2
3	1808	1610	1288	949	2167	1756	1525	1193	3
4	1566	1394	1116	822	1876	1521	1321	1033	4
6	1279	1138	911	671	1532	1242	1078	843	6
10	990	882	705	520	1186	962	835	653	10

Table 62—PIPE LINE CAPACITIES

Quantity expressed in thousands of Cubic Feet per 24 hours
Atmospheric Pressure 14.4 Temperature 60 deg. fahr. Specific Gravity 1.00
For Specific Gravity Factors see page 197

Length of Pipe Line in Miles	Intake Pressure 15 Lb. per Sq. Inch				Intake Pressure 25 Lb. per Sq. Inch				Length of Pipe Line in Miles
	Discharge Pressure				Discharge Pressure				
	25″ Vac.	0 Lb.	6 Lb.	10 Lb.	25″ Vac.	0 Lb.	10 Lb.	15 Lb.	
2 Inch Pipe Line									
¼	271	237	196	152	393	339	285	242	¼
½	192	167	138	107	256	239	201	171	½
1	136	118	98	76	181	169	142	121	1
2	96	84	69	53	128	119	100	85	2
3	78	68	57	44	104	97	82	70	3
2½ Inch Pipe Line									
½	335	293	242	187	450	419	353	300	½
1	237	207	171	133	318	297	250	212	1
2	168	146	121	94	225	210	186	150	2
3	137	120	99	77	184	171	144	122	3
4	119	104	86	66	159	148	125	106	4
3 Inch Pipe Line									
½	534	466	385	298	715	667	561	477	½
1	377	330	272	211	505	471	397	337	1
2	267	233	193	149	357	333	280	239	2
3	218	190	157	122	292	272	229	195	3
4	189	165	136	106	252	235	198	169	4
4 Inch Pipe Line									
½	1103	964	796	617	1479	1377	1163	986	½
1	780	682	563	436	1045	973	821	697	1
2	552	482	398	308	739	688	581	493	2
3	451	394	325	252	576	560	473	403	3
4	390	341	282	218	521	486	409	349	4
6	318	278	230	178	427	398	335	284	6
5 Inch Pipe Line									
½	1940	1697	1401	1086	2604	2428	2047	1736	½
1	1372	1200	991	768	1841	1716	1447	1227	1
2	970	848	701	543	1302	1214	1023	868	2
3	792	692	572	443	1062	990	835	708	3
4	686	600	495	394	921	858	724	614	4
6	560	490	404	313	751	700	591	501	6
6 Inch Pipe Line									
1	2173	1819	1569	1215	2912	2712	2290	1681	1
2	1537	1343	1109	859	2061	1919	1615	1374	2
3	1258	1099	908	703	1684	1569	1319	1125	3
4	1087	950	784	608	1452	1356	1141	971	4
6	887	775	640	496	1190	1108	935	793	6
10	687	601	496	384	923	859	724	614	10
8 Inch Pipe Line									
1	4529	3957	3269	2532	6070	5653	4773	4048	1
2	3203	2799	2312	1791	4296	4000	3367	2863	2
3	2616	2286	1818	1463	3511	3270	2749	2338	3
4	2265	1979	1635	1266	3027	2826	2378	2025	4
6	1848	1615	1334	1034	2480	2310	1949	1652	6
10	1432	1252	1034	801	1921	1790	1510	1280	10

Table

COMPARATIVE CAPACITY OF PIPES OF DIFFERENT GAS APPLIED TO LINES IN WHICH A

Size of Pipe In.	1	2	3	4	5	6	8
	Comparative Note—In making computations observe						
1	1	34	265	1,150	3,573	9,035	39,000
2	.0294	1	7.8	34	105	266	1,150
3	.0037	.128	1	4.34	13.45	34	147
4	....	.0295	.231	1	3.11	7.80	34
5	....	....	.0741	.3274	1	2.51	10.94
6	....	....	.0293	.1272	.3954	1	4.34
8	....	....	.0037	.0295	.0915	.2316	1
10	....	....	....	.0094	.0295	.0741	.3260
12	....	....	....	....	.0116	.0295	.1272
15¼	....	....	....	....	....	.0086	.0373
16	....	....	....	....	....	....	.0295
17¼	....	....	....	....	....	....	....
18	....	....	....	....	....	....	....
19¼	....	....	....	....	....	....	....
20	....	....	....	....	....	....	....

The above table is based upon the fact that the length of pipes for the same quantity of gas varies as the 5.0835 power of their diameters. The value of the increasing or decreasing sizes can readily be appreciated by an inspection of the table.

It is particularly useful in securing the value of a series of different sizes of pipes in the same line by reducing the values of the several sizes to some one of the sizes in use. For example, on the horizontal line in the table a unit, say 1 foot or 1 mile of 8 inch pipe,

63
DIAMETERS CONVEYING THE SAME QUANTITY OF NUMBER OF DIFFERENT SIZES ARE USED

(By F. H. Oliphant)

10	12	15¼	16	17¼	18	19¼	20

VALUES
carefully the decimal notations.

121,210	306,380	1,043,700	1,326,000	1,937,700	2,406,100	3,382,300	4,120,000
3,570	9,035	30,700	39,000	57,000	70,765	99,480	121,178
457	1,150	3,940	5,004	7,312	9,040	12,760	15,550
105	265	908	1,150	1,685	2,092	2,940	3,575
34	85.75	292	371	542.3	673.4	946.6	1,150
13.45	34	115.5	147	215	265	375	457
3.11	7.80	26.75	34	50	61.70	86.70	105
1	2.52	8.61	10.94	16	19.85	27.90	34
.3954	1	3.41	4.34	6.32	7.80	11.00	13.45
.1161	.2935	1	1.27	1.85	2.30	3.24	3.95
.0915	.2316	.7871	1	1.46	1.81	2.55	3.11
.0630	.1582	5386.	.6843	1	1.24	1.75	2.13
....	.1273	.4337	.5510	.8053	1	1.41	1.71
....	....	.3085	.3920	.5728	.7113	1	1.22
....	....	....	.3218	.4703	.5840	.8209	1

has the same value as 3.11 feet or miles of 10 inch, 7.80 feet or miles of 12 inch and 105 feet or miles of 20 inch.

When smaller sizes are used 1 foot or 1 mile of 8 inch pipe is equivalent to 0.2316 feet or mile of 6 inch pipe, etc.

Larger diameters, when compared to smaller, give the equivalent in an increased length, and smaller diameters give a less length when compared with a diameter assumed to be 1.

Fig. 46—GENERAL VIEW OF DRUMRIGHT GASOLINE PLANT OF TIDAL REFINING COMPANY

PART NINE

Air in Casinghead Gas

ELIMINATING AIR FROM SUCTION LINES—HAYES GAS ANALYZER

Effects and Detection of Air in Gas at Gasoline Plants* —" The maximum pressure that can be built up by gasoline vapor is dependent only on the quantity of gasoline available for forming vapor and on the temperature of the gasoline. Because these conditions are quite constant in an oil bearing sand, the quantity of gasoline vapor that may be supplied to a cubic foot of pore space may be looked upon as quite constant. At most, it will change at a very slow rate. From this fact, it will be seen that the ratio of gasoline vapor to other gases rises rapidly as the total pressure of the gas mixture falls. That the production of gasoline increases as the rock pressure of a well decreases, is a fact of wide experience. Many observations indicate that natural gas is seldom, if ever, saturated with gasoline vapors. This is to be expected as the contact of gas and oil is never sufficiently intimate to make saturation possible.

The main components of natural gasoline are pentane, hexane and heptane. Other hydrocarbons both higher and lower in the series are present. The quantities of heptane and higher members are usually small. Pentane and lower members contribute "wildness" to the gasoline and therefore a large proportion of these is lost in the weathering of the raw gasoline. For purposes of this discussion, we may confine our attention to hexane and use its properties to get an insight into this phase of the production of natural gasoline. Hexane is a liquid boiling at 156 deg. fahr., and shows a

* By Dr. O. J. Sieplein.

specific gravity of 81 deg. Baume. At 100 deg. fahr. (a frequent temperature of oil strata) hexane exerts a total vapor pressure of 5⅓ pounds. Let us assume that the gas and oil are present in the sand under conditions which make possible the building up of two pounds pressure for the vapor of hexane. This will mean that the gas contains 37½ per cent of the saturation quantity of hexane vapor. The following table shows the relation of total pressure to vapor content for such conditions; the last column is added to indicate the gauge pressure at which the precipitation of gasoline would commence. Doubling this pressure would condense one-half the vapor present; gas with one per cent of vapor would yield about one-sixth of a gallon of liquid gasoline when this doubled pressure is used.

Table 64

Absolute Pressure	Gauge Pressure	Per cent Hexane	Precipitation Pressure
200 lb.	185 lb.	1 per cent.	518 lb.
100 lb.	85 lb.	2 per cent.	253 lb.
30 lb.	15 lb.	6⅔ per cent.	65 lb.
15 lb.	Atmospheric	15 per cent.	25 lb.
10 lb.	10 in. vacuum	20 per cent.	25 lb.
5 lb.	20 in. vacuum	40 per cent.	4 in. vacuum
2½ lb.	25 in. vacuum	80 per cent.	16 in. vacuum
2 lb.	26 in. vacuum	100 per cent.	20 in. vacuum

These figures show that the lower the total pressure, the higher is the relative quantity of gasoline vapor and therefore the larger is the yield of gasoline from handling a given quantity of gas in the plant. The recognition of this fact has led many companies to operate under vacuum conditions. As soon as possible after connecting a well, the service line to the gasoline plant is connected with pumps powerful enough to overcome the rock pressure and create a vacuum. As the rock pressure is reduced by exhausting the gas reservoir, it becomes advantageous to use gas-pumps to obtain larger quantities of richer gas.

As soon as the gas pumps handle the gas so as to produce any vacuum on the lines, leaks in these field lines become of grave importance to the operation of the plant. They introduce an element of danger and seriously reduce the production of gasoline; this danger and reduction of output is of course, due to the air drawn into the lines and mixed with the gas. As long as there is pressure on the lines, leaks are quite apparent and are easily detected; there is no opportunity for these to cause contamination of the gas with air—the only effect is loss of gas. With lines under vacuum, detection of leaks becomes more difficult and every leak means air is added to the gas. Leaks on vacuum lines may go undetected for a long time under ordinary field conditions. The best method for detecting leaks in such lines is to throw them temporarily out of service and connect with gas or air under pressure. The exhaust from the gasoline plant may very feasibly be used for this purpose. Because of the dangers and losses attendant on handling a mixture of air and gas, it is important to the efficiency of operation that all vacuum lines be tested for leaks very frequently.

At booster stations or other compression pumps, it may happen that with improper working of the feed, the pump will draw in a full supply of air and send this into the discharge pipe as a slug. In such cases the slug of air may travel a great distance without mixing with the gas in the line. When this slug comes to a burner the flame is extinguished because of lack of fuel; afterward gas passes through the burner and may collect as such, constituting an element of danger, especially in household and other small installations.

The air slug may be mixed with the gas to such extent that we have an explosive mixture fed to the burner. Occasionally the explosion will strike back into the line and wreck the line. Fortunately the introduction of air as slugs in the above manner is rather rare and the danger of

extinguishing the flame is rather unusual. Explosive mixture is more commonly the result of leakage of air into the line when the line is under vacuum. This gives a rather uniform mixture of gas and air which may be in explosive ratio and ignited at the burner as suggested above. Ignition of the mixture may result inside the line by means of a pebble rolled along the pipe, which when striking an obstruction in the pipe gives rise to a spark.

Addition of air accompanied by complete mixing with the gas acts in diluting the gas. When delivered to the burners we have reduced thermal efficiency because the burner is furnished with a lesser quantity of gas per minute. The well known, flickering, yellowish flame of natural gas is shown when burning takes place at burners without adequate mixers at the control valve. In rich, wet gas the flame is strongly yellow and may even show soot. As increasing quantities of air are mixed with the gas coming to the burner, the flame becomes steadier and less luminous; then with properly set mixer we have the steady efficient blue flame with well defined inner cone of light blue color. As the air content increases still more, the flame becomes shorter and finally blows away from the burner. These facts may be used to detect air in gas which is used in burners.

During compression gases are heated in response to the pressure. The amount of heating depends upon the nature of the gas and the heating effect depends on the opportunity for radiation of the heat generated. The heating effect in a completely insulated cylinder for gases at 60 deg. fahr. is shown in the following table:

Table 65

	Temperature reached at		Increase of Temperature at	
	250 lb.	500 lb.	250 lb.	500 lb.
Air....................	700 deg.	964 deg.	640 deg.	904 deg.
Dry Gas (Sp. Gr., 0.56)	573 deg.	752 deg.	513 deg.	692 deg.
Wet Gas (Sp. Gr., 1.04)	410 deg.	522 deg.	350 deg.	462 deg.

The table shows that when we compress air we have a much greater heating effect than when we compress natural gas. The table indicates also that the richer the gas the less the heating effect. A wet gas (sp. gr. 1.04) capable of producing three to four gallons of gasoline shows about two thirds of the heating effect of a dry gas and not much more than one half as much as air. This means that when the gas drawn into the compressor is contaminated with air we have a larger heating effect than with pure gas. The compressor will run hotter; more cooling will be necessary or the compressed gas will be hotter when delivered. This will reduce the effective compression, will cause more wear on the compressor and will mean more leakage past the compressing piston because of the more rapid wear. The gas is delivered to the cooling system in a warmer condition and therefore this system is rendered less efficient. The compressed gas reaches the accumulator tanks or gasoline traps with less perfect precipitation of the gasoline. The waste gas is less perfectly separated from its vapors; it is rich gas mixed with some air. Dry gas and wet gas such as indicated in the table require 10 and 17½ cubic feet of air respectively, for complete burning of one cubic foot of gas. Thus it takes a large addition of air to materially reduce the quantity of fuel value of the waste gas. This waste gas is usually used to drive the engines in the plant. When air is present the engines are fed with a mixture of unusually rich gas and air. This mixture fires too soon and burns too rapidly. The engine cylinder is improperly and unduly heated; the wear on the engine is excessive, its power delivery decreased.

The addition of air to gas means that the plant handles less gas when operating at a certain rate. The gasoline production is decreased because of the lesser quantity of gas handled. Gasoline vapor is carried out in the waste quite as effectively by air as by gas; in this we have a second loss of gasoline. One thousand cubic feet of wet gas con-

taining vapor capable of producing three gallons of gasoline will produce less than two gallons if mixed with one thousand cubic feet of air. One thousand cubic feet of such a mixture would probably not produce more than one-half gallon of gasoline with compression and cooling held at the same efficiency as when producing three gallons on pure gas.

The production of gasoline by compression does not begin until the pressure on the gas is sufficient to raise the pressure on the gasoline vapor to its saturation pressure for the working temperature. This pressure is indicated in the last column of Table 64. The effectiveness of the pressure on the gas is reduced by the presence of air. On a mixture containing 25 per cent air the effective pressure on the gas is $\frac{3}{4}$ of the total pressure; in a mixture containing 50 per cent air, the effective pressure is $\frac{1}{2}$ the total, etc. Thus the addition of air to gas increases the pressure that must be applied to start condensation, just in proportion as the gas is to the total mixture. To get a certain result it is necessary to increase the pressure in the same proportion as air is added. As the plant is usually run at a definite pressure, introduction of air shows a serious decrease in the production of gasoline.

To summarize, air is objectionable in gas handled in a compressor plant:

(1) Explosive nature of the material.

(a) Causes excessive wear on the engine because of preignition and rapid burning.

(b) May result in wrecking of pipe lines and other equipment.

(2) Inefficient production of gasoline

(a) because of improper cooling after compression.

(b) actual pressure in accumulators is lower.

(c) gasoline vapor is carried out by air in the waste gas.

(d) increases quantity of material handled.

(e) effective pressure on the gasoline vapor is less.

(3) Excessive wear on the compressors.

(a) because of higher temperature of operation.

(b) because the compressor cylinders are in contact with hot gas containing the oxygen of the air and are therefore corroded.

Air may be detected during the regular course of operation:

(1) By flames losing yellow color or blowing away from the burner.

(2) By increased temperature of the compression cylinders.

Because of its many dangerous and troublesome effects, air should be carefully excluded from gas and continual watch should be kept to prevent leaks in vacuum lines. Though the indications cited may be used to detect the presence of air, the only satisfactory proof is the chemcial test.

In the laboratory of the company we have developed a small detector which can be used to get an idea of the presence of air. This detector cannot take the place of the regular laboratory test which determines the quantity of air, but can be used to show whether the gas is free from air, slightly contaminated or badly contaminated. It consists of a small glass tube into which is sealed a piece of white paper so sensitized that it will turn brown on exposure to air. The gas to be tested is led through an ordinary rubber gas hose. When the air has all been swept out of this hose, the glass tube (still sealed) is inserted into the hose. The tips of the tube are now broken off; thus the gas streams through the tube in contact with the sensitized paper. The rate at which the paper changes color gives a rough idea of the amount of air present. In a current of pure air the color changes within a few seconds."

AIR IN CASINGHEAD GAS

It is good policy to take samples of the gas from each of the main field lines monthly or even weekly and to make an analysis of them for oxygen.

Instances have been known to the writer where a gasoline plant, after running for several weeks, did not produce the quantity of gasoline per thousand cubic feet of gas treated that the preliminary tests, which included the portable compressor tests, showed the gas carried. After an extended investigation of the plant, lines, etc., the trouble was located in defective casingheads, which permitted the entrance of air into the lines due to the vacuum on the wells and lines. It was then evident that the reason for the low production of gasoline from the gas at this particular plant was due to the fact that the plant was receiving a mixture of casinghead gas and air. After the lines and casingheads were placed in gas tight condition the production of gasoline increased to a greater amount per thousand cubic feet of gas treated than the portable compressor test had shown in preliminary tests.

In addition to the production loss at the plant, there was a loss in the air passing through the meter and being registered the same as gas. In other words, all the air that leaked into the lines back of the meter was charged at the same rate as the gas.

In another case, the analysis of casinghead gas from one well showed as much as 65 per cent air while being pumped under vacuum pressure. This was due to a loose fitting two inch plug in the casinghead.

It is good policy to have the pipe lines on each lease or group of leases so arranged that it is possible to put a pressure on them to determine any leakage. If the natural pressure of the casinghead gas when shut in, does not run up high enough, it is possible to shut the stops on lines running to the lease and connect the residue gas line to

them. As the residue gas is generally under a pressure of twenty-five pounds or greater, the test for leakage can be made with this gas. Invariably the leakage on a system of lines is due to many leaks of small size. All leaks, however small, should be stopped.

It is hardly necessary to mention that a mixture of casinghead gas and air would be liable to cause an explosive mixture, the same as found in a gas engine cylinder. All that would be lacking would be the spark. This might be caused by a pebble rolling along the inside of the pipe and hitting some obstruction.

Eliminating Air from Suction Lines—Air is one of the greatest sources of trouble in the operation of a casinghead plant. It causes trouble in the following ways:

First—Loss of Production—The air, in mixing with the casinghead gasoline mixes with vapors of the gasoline and raises the temperature and pressure required to liquefy the gasoline constituents to so high a point that the plant cannot properly condense and remove the gasoline.

Second—Damage to Plant Machinery—In many plants the effect of air in its action upon the engines is bad, owing to the gasoline not being extracted from the gas and being carried to the engines. A gas engine works in the same manner as a gasoline engine. Most gas engines have too high a compression to take gasoline gas without pre-ignition. Gasoline engines should not have over 75 pounds compression. When the rich mixture of air and casinghead gas strikes the engines, it causes excessive heating in the cylinder due to pre-ignition and a quick burning of the charge. This causes frequent shut downs and often it becomes necessary to rebore the cylinders. As the plant becomes older and the vacuum on the sand increases, the engine trouble increases, due to greater leakage of air. Engines have been known to become so hot from

running on mixtures of air and gas as to melt the ignition apparatus inside the cylinders. The cost of operating a plant suffering from air troubles runs to an excessive figure from engine repairs alone.

THIRD—Increased Cost of Gas Due to Mixture of Air—The amount of gas decreases directly in proportion to the amount of air in it and this loss is considerable. However, it is much less than the two losses noted above. Plants have been built on a showing of gas amounting to from three to four hundred thousand cubic feet, and when the air has been eliminated, the quantity of gas remaining has fallen off considerably, owing to the fact that the gas as originally measured contained more than 50 per cent air.

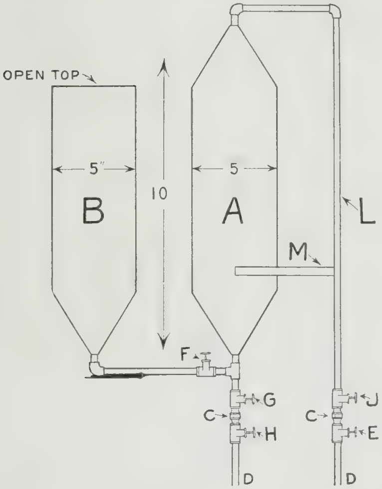
Most gas pumps will show 9 to 10 per cent air. The ordinary pump in good condition will show not over 14 per cent. Wells and lines on some leases in poor condition will show from 35 to 65 per cent air. Most of this leakage takes place around the casinghead, or in the casing. Stuffing boxes on pumps also cause trouble.

In a general way it may be said that the effects of air are cumulative, that is, the admission of air causes troubles which in turn create still others, until the plant operator has so much expense on his hands that most of the profit from plant operation is lost.

Conversely, removing air will decrease the amount of work to be done by the engines at the plant; the working pressure can be lowered as the gas will be richer and easier to handle, and the engines will operate under more favorable conditions, as they have better gas on which to do the work.

If air cannot be eliminated, it is best to reduce the compression of the engines by using deeper cylinder heads. Compression rings, owing to the insulating effect of the gaskets adjoining them, have a tendency to become hot and cause pre-ignition. Increasing the water flow to the jackets will also assist in keeping the cylinders cool.

SAMPLE UNDER VACUUM



A—Sample collecting tube or tank.
B—Water storage tank.
C—Three-eighth inch union.
D—Three-eighth inch tap in gas line.
E, F, G, H, J—Three-eighth inch wheel valves.
L—Three-eighth inch pipe.
M—Brace to hold L and A in relative position.

Fig. 47—APPARATUS FOR TAKING SAMPLE OF GAS FROM PIPE LINE UNDER VACUUM

Taking Sample of Gas from a Pipe Line under a Vacuum—Figure 47 shows the apparatus for taking a sample of gas from a pipe line under a vacuum.

To take a sample of gas proceed as follows:

Make two three-eighths inch taps on top of the gas line the proper distance apart to fit similar connections on the sampling outfit. Screw in each tap a three eighths inch

nipple with wheel valve and in each valve screw a short nipple with a half of a three-eighths inch union. The face of the union in each connection should be the same distance from the pipe line.

Before attaching portable sampling outfit to the three eighths inch connections on the pipe line, close valve F, invert apparatus and fill tank A with water while both valves G and J are open. After filling close valves G and J.

Fill the pipe connections on the pipe line between H and C and between E and C with water. Place the apparatus with all the valves closed and connect unions C and C. Make sure that there are no leaks in any of the connections.

After attaching apparatus fill the storage tank B to the top with water.

To obtain the sample, open valves G and H, and then valves J and E. Water will flow into the pipe line and the gas will flow through pipe L into tank A. After allowing sufficient time for the water to flow out of the tank, close valves G and J and then open valve F, allowing the water to flow from the storage tank B into A. After the water has equalized between A and B close valve. Repeat the operation of flowing the water from A into the pipe line by opening valves G and J. This second operation greatly assists in obtaining a true sample.

Close all valves and remove apparatus by disconnecting unions C and C. To overcome the vacuum in the sample of gas, refill B and allow water to flow into A by opening valve F.

The sample of gas can be forced out of pipe L, from A into pipette by placing water in B and opening the valve F.

Connections D-H and D-E can be left in the pipe line permanently.

HAYS GAS ANALYZER*

To make a Gas Analysis is an exceedingly simple matter, but like many other simple operations every step must be thoroughly understood. The beginner will do well to fix each step in his mind before taking up the next one—otherwise he may become confused and have to start again at the beginning.

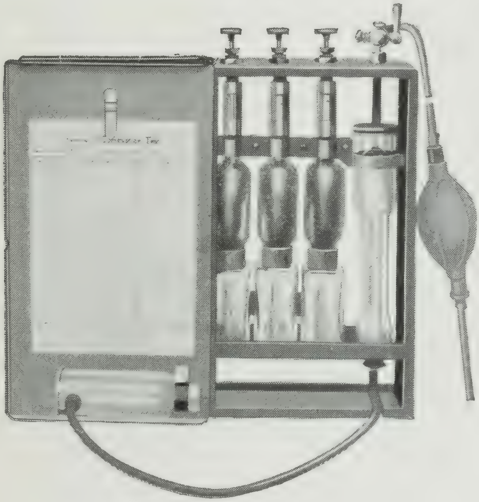


Fig. 48—HAYS GAS ANALYZER

A mixture of Gases is analyzed by the "Volumetric Method"—that is, a measured volume of the mixture is taken and one of the gases is removed by absorption. The volume remaining is then measured and the shrinkage indicates the percentage of the gas absorbed. The residue volume is then exposed to another absorber which removes another gas. On re-measurement the volume of that gas becomes known, and so on until all of the gases have been determined. The "volu-

* Courtesy of the Joseph W. Hays Corp.

metric method" is employed because it is exceedingly difficult to weigh gases. If the weights are desired these can be easily computed when the percentages by volume are known.

Gases expand or contract very rapidly when subjected to changes of temperature. The volume of a gas also depends upon the pressure to which it is subjected. For these reasons it is necessary that all measurements of volume during the process of analysis must be made under the same conditions of temperature and pressure. It makes no material difference what the temperature or pressure may be so long as neither is subject to change while the sample is being analyzed. The "Burette" in which the gases are measured is water-jacketed. This controls the temperature. All measurements are made at atmospheric pressure by means of the "Leveling Bottle."

Referring now to the illustration of the Analyzer and to Figures 50 and 51:

You will observe a tube at the right of the Instrument Case, having a scale from 0 to 21 etched upon it. This is the "Burette." The scale reads upward from 0 to 21 per cent and the divisions are in fifths of a per cent.

The "Burette" is enclosed in a glass tube, known as the "Water-Jacket"—the latter being closed at the top with a rubber cap.

"The "Leveling Bottle" is attached by a rubber tube to the bottom of the Burette. Please note how the bottle is held by clips (shown in the illustration) on the door of the Instrument Case.

Stand the Instrument upright upon a table and remove the Leveling Bottle from the Clips. When in use in a boiler room or elsewhere the Instrument should be hung upon a nail, using the hole in the back of the case near the top. (The Leveling Bottle may then be hung by its hook upon the flanges at the bottom of the case, as shown in the illustration.)

You will note that the Instrument is provided with three Absorber Containers. The bulbs of two of the Containers

are packed with Steel Wool. The bulb of the third one is packed with Copper Wire and there is some scrap copper in the bottle below.

The Container nearest the Burette is to be charged with the absorber for CO_2 (a solution of Caustic Potash). The middle Container is for the Oxygen absorber (a solution of Pyrogallic Acid and Caustic Potash), and the one containing the copper is for the Carbon Monoxide (CO) absorber (an ammoniacal solution of Cuprous Chloride).

Bottles containing the three solutions will be found among the supplies furnished with the Instrument.

Fig. 49—CARRYING CASE FOR GAS ANALYZER

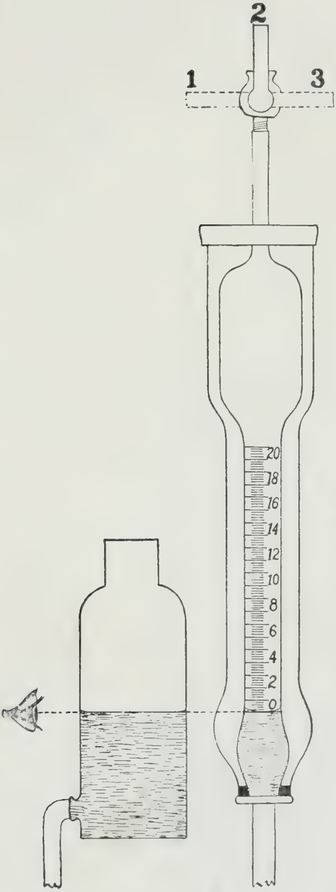


Fig. 50

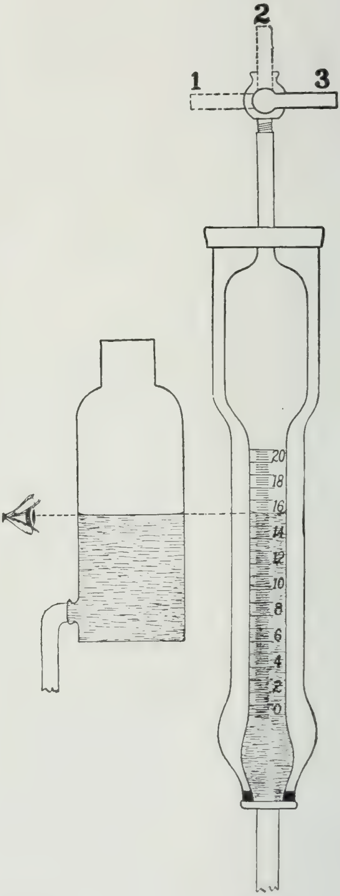


Fig. 51

PREPARING THE INSTRUMENT

1. Fill the Leveling Bottle with CLEAR Water.

2. Note the "Three-way Cock" at the top of the Instrument Case, immediately above the Burette. The Cock has three positions (see Figures 50 and 51). When operating the Instrument you will stand on that side of it upon which the scale of the Burette appears. When the handle of the Cock is in a horizontal position, pointing towards you, Gas can be pumped through the Burette and will bubble out through the water in the Leveling Bottle. When the handle is in a vertical position, as shown in the illustration, the Burette is open to the air and when it is in a horizontal position pointing away from you the Cock is closed.

3. If the Cock does not operate freely use a few drops of oil, applying same on the plug of the cock. A little vaseline, if it is available, will answer the purpose better than the oil. You can very easily remove and replace the plug.

4. With the Handle of the Cock in a VERTICAL POSITION, raise the Leveling Bottle. This will cause water to flow from the bottle through the connecting rubber tube into the Burette. The air in the Burette will be expelled through the Cock. Fill the Burette in this manner until the water "pinches out" in the capillary tube at the top, then turn the Handle of the Cock into the horizontal position, POINTING AWAY FROM YOU. This closes the Cock and if everything is tight the water will "hold" in the Burette after you have lowered the Leveling Bottle. If the water falls in the Burette turn the three "Thumb-Cocks" of the "Needle Valves," at the top of the Instrument Case to the right.

5. Lift the Rubber Cap at the top of the Water Jacket and fill the latter with CLEAR water. Make sure that the Cap is properly replaced after filling the Jacket, otherwise the water will spill out when you are carrying the Instrument. The water will last indefinitely as the cap will prevent evaporation.

6. Remove the Stopper from the tube at the rear of the Absorber Container nearest the Burette (the one for the CO_2 Absorber.)

7. You will find among the supplies a short length of rubber tubing with a short piece of glass tubing in one end. Connect this with the tube from which the Stopper was removed. Insert the rubber tube in the bottle labeled "Caustic Potash Solution."

8. Turn the "Thumb-Cock" of the Needle Valve to the left and lower the Leveling Bottle. The Caustic Solution will be drawn into the Absorber Container. When the water reaches the bottom of the Burette close the Needle Valve and raise the water again to the top of the Burette, as described in Paragraph 4. Reopen the Needle Valve and draw in the remainder of the Caustic. When properly filled the Caustic will stand in the Capillary Glass Tube above the Bulb of the Container and will seal the Glass Tube in the Lower Bottle at least one-quarter of an inch. If there is not sufficient Caustic add a little water.

9. The other solutions are introduced into their Containers in the manner described in Paragraph 8. The beginner is advised to become familiar with the use of the Instrument in the determination of CO_2 before charging with the Oxygen and CO solutions. These solutions deteriorate on exposure to light and air. Keep the bottles stoppered and in a dark place.

10. In ordinary practise you will have little use for the CO_2 and CO analyses. There is little danger of CO in casinghead gas.

11. You are now ready to make use of the Analyzer. Replace the stopper of the tube at the rear of the Caustic Container. Make sure that the Needle Valve is closed. Set the handle of the Three-Way Cock in Position 3, replace the Leveling Bottle in the Clips on the door of the Instrument Case, close the Case and the Instrument is in condition to be carried anywhere in any position.

OPERATING THE INSTRUMENT

12. Drive a nail in the side of the room, or wherever is convenient, and hang the Instrument upon it, opening both doors. Connect the rubber "Aspirator Tube" to the Three-way Cock and hang the "Leveling Bottle" upon the Instrument Case, or in a position close to case. Be sure that there is a good light at the back of the Instrument. Be sure also that the caustic is standing in the Capillary Tube about midway and that the Bulb of the Container is full. It is possible that there may be some caustic in the Capillary tube and that the bulb may be partially empty. In such case partly fill the Burette with air by lowering the Leveling Bottle, the Handle of the Cock being in Position 2. Place the Cock in Position 3, raise the Leveling Bottle and open the Needle Valve. This will force the Caustic out of the Capillary Tube into the Bulb. Next close the Needle Valve and Fill the Burette with water, then open the Valve and lower the Leveling Bottle (first setting the Cock in Position 3). This will draw the Caustic up to its proper position. BE CAREFUL AND DO NOT DRAW ANY CAUSTIC OVER INTO THE BURETTE.

13. You will note that the Aspirator Tube is supplied with a Filter, packed with cotton waste. This is to remove the dirt and other foreign matter from the gas before it enters the Instrument. The cotton should be changed from time to time. Connect the Aspirator Tube to the Sampling Pipe and insert the latter in the flow of gas. MAKE SURE THAT THE INTAKE END OF THE SAMPLING PIPE IS AT THE CENTER OF THE GAS FLOW. Bear in mind that unless the gas sample taken for analysis is a representative one your analysis will mean nothing.

14. Having connected the Sampling Tube, place the Handle of the Three-way Cock in Position 1 (see the Figures) and work the Aspirator Bulb. Gas will be pumped through the Burette and will bubble out of the Leveling

Bottle. Watch the Bulb of the Burette closely and if there is any moisture in the gas (usually there is some) you will see it condense in a whitish vapor. When this happens you will know that you have pumped the air out of the tube and are getting gas in the Burette. You will soon learn about how much pumping it takes to get a fair sample of gas into the Burette.

15. You are now ready to make a determination of the percentage of CO_2 in the gas sample that you have pumped into the Burette.

Now if you wished to learn how much chaff by volume there might be in a bushel of wheat you would first carefully measure out an exact bushel by volume of the mixture. You would take a bushel measure, fill heaping full and run a "straight edge" across the top of it. You would then remove the chaff and carefully measure the wheat. The steps that you take in making gas analysis are exactly analagous.

You have Gas in the Burette but more of it than required. Take the Leveling Bottle in your left hand and hold it close to the Burette, steadying your hand against the Instrument Case. Get your eye into the position shown in Figure 50 and turn the Handle cf the Three-way Cock into Position 2. Now, keeping your fingers on the Handle of the Cock, raise the Leveling Bottle until the water is on a level with the Zero mark on the scale of the Burette. Water will flow from the bottle into the Burette and drive the excess gas out through the air vent of the Cock. Keep the water level in the Bottle in the same horizontal plane as the Zero mark. To do this you will have to raise the bottle slowly as the water flows out of it.

You will notice that the water in the burette has a curved appearance. When the bottom of this curve, or "meniscus" as it is called, is on the Zero mark, push the Handle of the

Cock into Position 3. You have now made an exact measurement of the gas at atmospheric pressure and the gas is at the temperature of the water in the Jacket.

Making the first gas measurement is the most "ticklish" thing connected with a gas analysis. You must not lower the Leveling Bottle while making the measurement as this would cause water to flow from the Burette into the Bottle and air would be drawn in through the vent of the cock. This would mix with the gas and spoil the sample.

Having made the measurement and locked the gas in the Burette you will find if the Leveling Bottle is raised that the gas is compressed and the volume diminishes and that if you lower the Bottle the gas is rarified and the volume increases. If you put the bottle on the Zero mark the water in the Burette will return to Zero. This experiment should make it very clear to you how important it is to exercise care in making the original measurements and how necessary it is to make all measurements at atmospheric pressure.

16. The next step is to remove the CO_2 from the Gas in the Burette. Raise the Leveling Bottle with the LEFT hand and turn the Needle Valve above the Caustic Container to the Left. The gas will flow from the Burette into the Bulb of the Container. Watch the water in the Burette closely, paying no attention to the Container. You may push the gas over very rapidly until the water nears the top of the bulb of the Burette, when you must slow it up with the Leveling Bottle and proceed very slowly. When the water pinches out in the capillary tube above the Burette, close the Needle Valve by turning to the right. If you cannot pass the Gas from the Burette to the Container it will be because you have forgotten to remove the stopper from the tube at the rear of the Container.

The Gas has now been transferred to the Caustic Container and the Caustic Solution has absorbed the CO_2. The

gas passes into the bulb over the fibres of steel wool which are wet with the Caustic. The absorption is very rapid and you can immediately return the gas to the Burette.

17. Open the Needle Valve and lower the Leveling Bottle. Pay no attention to the water in the Burette. Watch the Caustic closely. You may bring the gas back very rapidly until the Caustic nears the top of the Bulb when you must slow it up with the Leveling Bottle and bring the solution up into the Capillary Tube. Stop the solution about midway of the tube and BE CAREFUL THAT YOU DO NOT DRAW ANY OF IT OVER INTO THE BURETTE.

18. Now bring your eye, the surface of the water in the Bottle and the bottom of the Meniscus in the Burette into the same horizontal plane as shown in Figure 51 and read the scale of the Burette (reading on the bottom of the Meniscus). Let the water in the Burette come where it will. Bring your eye and the water in the bottle into line with it. The gas is again at the temperature of the water in the Jacket and it is at atmospheric pressure.

19. If, for example, you find that the Meniscus is resting upon the second mark above the 10 per cent line. The reading is 10, 2-5ths per cent. Write it decimally 10.4 per cent.

20. To take another Gas Sample for analysis, throw the Handle of the Cock into Position 1 and work the Aspirator Bulb. The fresh gas will flush the stale gas out of the Burette. A determination of CO_2 can be made every 45 seconds with the Hays Improved Gas Analyzer, including the time taken to pump the gas into the Instrument.

21. The absorption of Oxygen and CO proceed very slowly and great care must be exercised in making the measurements. The solution used for Oxygen will absorb CO_2 and that used for CO will absorb all three gases. For these reasons you must first take out the CO_2 before trying for Oxygen and you must take out the Oxygen before analyzing for CO.

22. To determine Oxygen you first make a memorandum of the CO_2 reading and then pass the gas into the middle container, which you have charged with the Pyro solution. Allow the gas to remain for about one-half minute, then return to the Burette and measure, noting the reading. Return again to the Container and repeat the operation until you get two readings that are the same. You then proceed in like manner to absorb the CO.

Suppose after the CO_2 absorption the reading is 1.0 per cent, after the Oxygen Absorption 5.0 per cent and after the CO absorption 5.6 per cent. The analysis would be as follows:

CO_2	1.0%	
Oxygen	4 %	(5.0% less 1.0%)
CO	0.6%	(5.6% less 5.0%)

Multiply the percentage of Oxygen thus determined, by 4.78 to obtain the percentage of air in the sample. It is seldom necessary to determine the amount of CO_2, however the last absorption gives a good check on the amount of Oxygen, as the percentage in the second and third solutions should be practically the same.

Be sure that all of the CO_2 has been removed before trying for Oxygen and be doubly sure that all of the Oxygen has been removed before trying for CO.

One exposure is all that will be necessary to get all of the CO_2 when the Caustic Solution is fresh. The solution will be good for about 500 absorptions. If you think that the solution may be getting stale, pass the gas over a second time. If you get an additional absorption give the gas a little more time in the Caustic Container or change the solution.

23. To empty the Containers for re-charging, attach the filling tube to the tube at the rear of the Container, remove the water from the Leveling Bottle, open the Needle Valve, hold the Instrument on its side and blow through the Leveling Bottle.

24. If you get any of the solutions on your hands wash them at once with soap and water. Do not get any of the liquids on your clothes.

25. The capillary tubes of the Instrument can be cleaned without taking the apparatus apart. Remove the Needle Valves by loosening the packing nuts. You can then push a pipe-cleaner down through the capillary glass tubes into the bulbs of the Containers. By removing the Three-way Cock you can push a pipe-cleaner or a fine wire through the capillary tube into the bulb of the Burette. By passing a screw-driver through the hole in the back of the instrument case you can reach a small screw. Remove this and pass a pipe-cleaner through the "header" of the capillary tubes.

26. After using the Instrument a number of times you will notice that the water "jumps back" from the Leveling Bottle into the Burette when you release the Aspirator Bulb and that it is difficult, if not impossible, to pump gas through the Leveling Bottle. Change the cotton in the Dirt Filter. If the valves of the Aspirator Bulb do not work as they should take them out and clean them.

27. A bottle of Cleaning Solution is furnished with the Instrument. This is for use in the Burette. Empty the water from the Leveling Bottle, fill with the Cleaning Solution, raise to the top of the Burette and let it stand for about ten minutes. If this does not clear the glass, repeat the operation. Pour the cleaning solution back into the bottle. It will last indefinitely.

PART TEN

Measuring Casinghead Gas

CASINGHEAD GAS METERS, DENSITY FACTORS, METER CAPACITIES, VOLUME AND PRESSURE RECORDING GAUGE, ORIFICE METER.

When casinghead gas is purchased by the cubic foot it is necessary to provide some means of securing an accurate measurement of it. A meter is also desirable for checking the efficient operation of the plant. A casinghead gas meter is built for this character of work, whether the gas measured is under pressure or a vacuum.

Where the volume of gas to be measured exceeds 3,000 cubic feet per hour, (actual volume), the most practical and cheapest method of measurement is by a casinghead gas or large capacity meter. Many companies use a large capacity meter to measure a volume of gas as small as 2,000 cubic feet per hour.

While it is true that in the early days of large volume, high pressure gas measurement, the proportional meter bore a doubtful reputation, during recent years many improvements have been made in these instruments, and they have been brought to a high standard of efficiency and accuracy.

The casinghead gas meter is a most important instrument to the casinghead gasoline industry but without doubt there is less known about it by the actual caretaker than about any other piece of apparatus under his care. It is a hard-worked piece of machinery, receiving little care and attention. Many instances are known where large capacity meters although in constant use for a period of two years or longer, were not even cleaned. While as a rule it is not good policy to repair a meter in the field without subsequent

testing, there are a great many things that may happen to it which only call for the tightening of a nut or screw, or the replacing of some part that does not in any way affect the accuracy of the meter.

The casinghead gas meter, like any other sensitive instrument, needs attention. It is often blamed for a great deal of inaccuracy that should be charged to the pipe line. If a meter is believed to be inaccurate, it should be carefully tested by a competent meter man, and if any controversy exists, it would be policy to have the meter tested once a month and all records of tests kept on file at the gas company's office. When a gas company, selling to another company in the field, decides to have a test made, it is no more than fair (whether a disagreement exists or not) that the other interested party should be asked to have a representative present during the test. The results of the test should not be kept secret but should be held as common property between the two companies interested. Secrecy in testing meters often breeds trouble and creates a great deal of unnecessary dissatisfaction.

It is necessary to keep the meter clean and well drained, and to make a test for accuracy periodically. If the gas is measured under vacuum, either straight recording pressure or recording volume and pressure gauges are necessary.

In measuring casinghead gas with meters they should be tested at least once a month. This will keep them in accurate condition and prevent any dispute arising from inaccurate meter readings. In carrying out this policy the time necessary for each test will be found to be far less than when the meters are neglected. A meter is an automatic machine and it must be expected that it will give trouble unless given proper care.

It is absolutely impossible for the meter manufacturer to make a meter that will measure any gas accurately for

an indefinite period without proper attention being given it periodically.

Success and accuracy in the use of meters can only be obtained by the cooperation of the meter owner and the meter manufacturer and not by the manufacturer alone.

Measure gas at as low a pressure as possible. It is customary to measure gas on a four ounce basis although the pressure is a matter for agreement. A great many field companies purchase gas on an eight ounce basis. The slight advantage gained by this increased pressure is supposed to offset the small loss caused by the pipe line leakage.

Factory Proving—Casinghead gas meters are proved in the factory for volume with air at four inches water pressure corrected to the barometer and thermometer readings at time of test. The proving instruments used are the standard flow meter, funnel meter and a large prover. In field proving, an additional correction is made on the pressure for the difference between the specific gravity of the gas and the air (air being 1).

Over Capacity—All dry meters will work over capacity to a reasonable extent, especially the small sizes. For instance the 6,000 cubic feet per hour meter will measure accurately up to 7,200 cubic feet per hour. It is not good policy to take advantage of this over capacity constantly, but if used occasionally it will not injure the meter.

Invariably the differential above the rated capacity of the meter increases greatly out of proportion to the differential of the meter within capacity.

Range of Accuracy—A casinghead gas meter is tested and corrected to within two per cent of accuracy within the limits of its capacity.

Accurate measurement cannot be expected below a certain minimum volume which will vary according to the rated capacity of the meter.

A large capacity meter given proper care and used within its rated capacity will prove to be a wonderfully accurate measuring instrument.

Installation—It is essential to use the proper amount of pipe on the inlet of the meter as designated in the directions for installing. For instance, in the case of an 8 inch meter, at least eight feet or more of 8 inch pipe should be used into the inlet flange. The meters are tested under these conditions in the factory and if the directions are not followed (as by using 4 inch pipe directly into an 8 inch meter, or by placing an ell, gate, or regulator within less than eight feet from the inlet flange of an 8 inch meter) the tendency would be to create counter currents or eddies and cause the meter to run slow.

Condensation—All gas direct from the well carries more or less aqueous vapor.

Condensation in pipe lines, regulators and large capacity meters is caused by the difference in temperature of the gas and air. If the gas is warmer than the air the condensation will be on the interior of the pipe, regulator, or meter; and if the gas is colder than the air, the condensation will be on the exterior. This condensation is commonly called sweating, being the moisture condensed from the atmospheric surrounding the pipe.

Drain Cocks—All meters should be installed with drain cocks on the inlet and outlet bowls to keep the meter absolutely dry. Casinghead gas carries aqueous vapor as well as gasoline vapor, which might also find conditions en route from well to the meter that would cause it to condense into free water.

Gaskets—Use soft card board gaskets about $\frac{1}{16}$ inch thick. Apply white lead on both sides of the gasket.

Cleaning—The question is often asked, "How often shall we clean our meter?" This is a hard question to answer for the reason that there are no two conditions to be found

alike in the gas that passes through the meter. It is better to clean the meter too often than not often enough. One can judge by the condition the meter is found to be in at each cleaning.

DENSITY FACTORS OR MULTIPLIERS

A meter measuring gas at a low pressure will only measure accurately a volume of low pressure gas up to its rated capacity in cubic feet, while a field or high pressure meter will measure accurately a volume of low pressure gas at a high pressure far in excess of the rated capacity of the meter, entirely dependent upon the pressure.

The lower the pressure or greater the vacuum in inches of mercury, of a volume of gas measured, the less will be the actual amount of atmospheric pressure gas the meter will measure when it is working at its full rated capacity. For example:—

Table 66

Meter Reading	Pressure in inches of Mercury Vacuum	Multiplier or Density	Actual Amount of Gas Measured at Atmospheric Pressure
10,000	0–Atmos.	1.00000	10,000
10,000	10 inches	.65915	6,591
10,000	20 "	.31828	3,182

In measuring gas at a vacuum the same formula for determining the multiplier based on Boyle's law applies as in high pressure.

To illustrate: One cubic foot of gas at four ounce pressure contains a certain number of molecules. Take a cylinder of a diameter which will contain one cubic foot for each foot in length, fitted with a tight plunger.

If the plunger in the cylinder is placed at the one foot mark and the space thus formed is filled with gas to a pressure

of four ounces, the cylinder then holds one cubic foot at a pressure of four ounces. Now, if the plunger is moved outward to the two foot mark the space within the cylinder would measure two cubic feet and the one cubic foot of four ounce gas would expand to fill the space while the pressure would drop to slightly greater than 14 inches of mercury vacuum. To correct the two cubic feet of gas at 14 in. of mercury vacuum to a four ounce basis, multiply the two cubic feet by the multiplier for 14 in. mercury vacuum or approximately .5 as found in the four ounce multiplier table on page 236, and the result will be one cubic foot of four ounce gas.

Fig. 52—ILLUSTRATION OF DENSITY OF GAS UNDER 4 OZ. PRESSURE AND 14 INCHES MERCURY VACUUM

NOTE—Pressure in cuts are gauge pressures

As all gas meters in the factory are proved and corrected to a low pressure basis, measuring gas by displacement, they may be compared to the cylinder and the plunger as illustrated above. In measuring gas in the meter, the diaphragms contain just so much space. If the pressure of the gas contained in each quantity or volume of gas measured by the diaphragm filling and discharging is four ounce, then the meter reading needs no correction; but each time the meter diaphragm fills and discharges a volume of gas at a pressure higher or lower than four ounces, the meter reading must be corrected by applying a multiplier, or density factor, to reduce the volume of gas measured to a four ounce basis; and the higher the pressure the greater will be the density of the gas and the lower the pressure below the four ounce base the less the density of the gas, and the greater or less the number of molecules contained in each cubic foot of space.

The multipliers for density are based on Boyle's law written in 1660, that the "volume of a gas varies inversely as the pressure."

While the four ounce basis is generally accepted when no other pressure basis is stated in buying and selling agreement, some other basis can be used and very often is used, particularly when gas is bought or sold in large volumes in the field.

Formula for Quantity of Natural Gas Measured Above or Below Normal Pressure—In which

For pressure above atmospheric pressure	For pressure below atmospheric pressure
$Q=q\,\dfrac{A+p}{A+.25}$	$Q=q\,\dfrac{A-p}{A+.25}$

Q = cubic feet required.

q = cubic feet shown by the meter.

p = gauge pressure in pounds.

A = atmospheric pressure (usually 14.4 pounds).

0.25 = 4 ounce pressure reduced to pounds.

By substituting the known values in the above it becomes $Q=q\,\dfrac{14.4+p}{14.4+.25}$ or $Q=q\,\dfrac{14.4-p}{14.4+.25}$

Example:

As 1 inch of mercury, = .4908 lb. to determine the multiplier for 10 in. vacuum pressure, then the formula becomes:

$$Q=\frac{14.4-4.908}{14.65}=.64790$$ multiplier for 10 in. mercury vacuum, for a 4 oz. pressure base.

Table 67

DENSITY FACTORS OR MULTIPLIERS FOR VARIOUS PRESSURES AND PRESSURE BASES

Gauge Pres. Inches Mercury Vacuum	Pressure Bases				
	2 oz.	4 oz.	8 oz.	10 oz.	1 lb.
—28	.04527	.04488	.04413	.04376	.04270
—27	.07906	.07838	.07707	.07643	.07457
—26	.11285	.11188	.11031	.10909	.10644
—25	.14660	.14535	.14291	.14172	.13827
—24	.18039	.17885	.17585	.17439	.17014
—23	.21418	.21236	.20879	.20706	.20201
—22	.24798	.24586	.24173	.23972	.23389
—21	.28177	.27936	.27468	.27239	.26576
—20	.31556	.31287	.30762	.30506	.29763
—19	.34935	.34637	.34056	.33772	.32950
—18	.38314	.37987	.37350	.37039	.36137
—17	.41693	.41338	.40644	.40306	.39324
—16	.45073	.44688	.43938	.43573	.42512
—15	.48452	.48038	.47232	.46839	.45799
—14	.51831	.51389	.50526	.50106	.48880
—13	.55210	.54739	.53820	.53373	.52073
—12	.58590	.58090	.57115	.56639	.55260
—11	.61970	.61440	.60409	.59906	.58447
—10	.65348	.64790	.63703	.63173	.61634
— 9	.68727	.68141	.66997	.66439	.64822
— 8	.72107	.71491	.70291	.69706	.68009
— 7	.75485	.74841	.73585	.72973	.71196
— 6	.78865	.78191	.76879	.76240	.74383
— 5	.82244	.81542	.80173	.79506	.77570
— 4	.85623	.84892	.83467	.82773	.80757
— 3	.89002	.88242	.86761	.86040	.83945
— 2	.92381	.91593	.90056	.89306	.87132
— 1	.95760	.94943	.93350	.92573	.90319
Atmos.	.99139	.98293	.96644	.95840	.93506
Lb. per Sq. In.					
.125	1.00000	.99146	.97483	.96672	.94318
.25	1.00860	1.00000	.98322	.97504	.95129
.5	1.02581	1.01706	1.00000	.99168	.96753

— Indicates Vacuum.

Table 68

DENSITY FACTORS OR MULTIPLIERS FOR VARIOUS PRESSURES AND PRESSURE BASES

Gauge Pressure Lb. per Sq. In.	Pressure Bases				
	2 oz.	4 oz.	8 oz.	10 oz.	1 lb.
.625	1.03442	1.02559	1.00838	1.00000	.97564
1	1.06024	1.05119	1.03355	1.02495	1.00000
1.5	1.09466	1.08532	1.06711	1.05823	1.03246
2	1.12908	1.11945	1.10067	1.09151	1.06493
2.5	1.16351	1.15358	1.13422	1.12479	1.09740
3	1.19793	1.18771	1.16778	1.15806	1.12987
3.5	1.23235	1.22184	1.20134	1.19134	1.16233
4	1.26678	1.25597	1.23489	1.22462	1.19480
4.5	1.30120	1.29010	1.26845	1.25790	1.22727
5	1.33562	1.32423	1.30201	1.29118	1.25974
5.5	1.37005	1.35836	1.33557	1.32445	1.29220
6	1.40447	1.39249	1.36912	1.35773	1.32467
6.5	1.43889	1.42662	1.40268	1.39101	1.35714
7	1.47332	1.46075	1.43624	1.42429	1.38961
7.5	1.50774	1.49488	1.46979	1.45757	1.42207
8.	1.54216	1.52901	1.50335	1.49084	1.45454
8.5	1.57659	1.56313	1.53691	1.52412	1.48701
9	1.61101	1.59726	1.57046	1.55740	1.51948
9.5	1.64543	1.63139	1.60402	1.59068	1.55194
10	1.67986	1.66552	1.63758	1.62396	1.58441
10.5	1.71428	1.69965	1.67114	1.65723	1.61688
11	1.74870	1.73378	1.70469	1.69051	1.64935
11.5	1.78313	1.76791	1.73825	1.72379	1.68181
12	1.81755	1.80204	1.77181	1.75707	1.71428
12.5	1.85197	1.83617	1.80536	1.79034	1.74675
13	1.88640	1.87030	1.83892	1.82362	1.77922
13.5	1.92082	1.90443	1.87248	1.85690	1.81168
14	1.95524	1.93856	1.90604	1.89018	1.84415
14.5	1.98967	1.97269	1.93959	1.92346	1.87662
15	2.02409	2.00682	1.97315	1.95673	1.90909
16	2.09294	2.07508	2.04026	2.02329	1.97402
17	2.16178	2.14334	2.10738	2.08985	2.03896
18	2.23063	2.21160	2.17449	2.15640	2.10389
19	2.29948	2.27986	2.24161	2.22296	2.16883
20	2.36833	2.34812	2.30872	2.28951	2.23376

Table 69

DENSITY FACTORS OR MULTIPLIERS FOR VARIOUS PRESSURES AND PRESSURE BASES

Gauge Pressure Lb. per Sq. In.	Pressure Bases				
	2 oz.	4 oz.	8 oz.	10 oz.	1 lb.
21	2.43717	2.41638	2.37583	2.35607	2.29870
22	2.50602	2.48464	2.44295	2.42262	2.36363
23	2.57487	2.55290	2.51006	2.48918	2.42857
24	2.64371	2.62116	2.57718	2.55574	2.49350
25	2.71256	2.68941	2.64429	2.62229	2.55844
26	2.78141	2.75767	2.71140	2.68885	2.62337
27	2.85025	2.82593	2.77852	2.75540	2.68831
28	2.91910	2.89419	2.84563	2.82196	2.75324
29	2.98795	2.96245	2.91275	2.88851	2.81818
30	3.05679	3.03071	2.97986	2.95507	2.88311
31	3.12564	3.09879	3.04697	3.02163	2.94805
32	3.19449	3.16723	3.11409	3.08818	3.01298
33	3.26333	3.23549	3.18120	3.15474	3.07792
34	3.33218	3.30375	3.24832	3.22129	3.14285
35	3.40103	3.37201	3.31543	3.28785	3.20779
36	3.46987	3.44027	3.38255	3.35440	3.27272
37	3.53872	3.50853	3.44966	3.42096	3.33766
38	3.60757	3.57679	3.51677	3.48752	3.40259
39	3.67641	3.64505	3.58389	3.55407	3.46753
40	3.74526	3.71331	3.65100	3.62063	3.53246
41	3.81411	3.78156	3.71812	3.68718	3.59740
42	3.88296	3.84982	3.78523	3.75374	3.66233
43	3.95180	3.91808	3.85234	3.82029	3.72727
44	4.02065	3.98634	3.91946	3.88685	3.79220
45	4.08950	4.05460	3.98657	3.95341	3.85714
46	4.15834	4.12286	4.05369	4.01996	3.92207
47	4.22719	4.19112	4.12080	4.08652	3.98701
48	4.29604	4.25938	4.18791	4.15307	4.05194
49	4.36488	4.32764	4.25503	4.21963	4.11688
50	4.43373	4.39590	4.32214	4.28618	4.18181

Table 70—METER CAPACITY REQUIRED TO MEASURE CASINGHEAD GAS

Atmospheric Pressure 14.4 | Expressed in Cubic Feet per Hour | Pressure Base 4 oz.

Maximum Volume per 24 Hours	Maximum Volume per Hour	Gauge Pressure Mercury Vacuum					
		5 in.	10 in.	15 in.	20 in.	25 in.	27 in.
5,000	208	5C	5C	9C	17C	17C	3M
10,000	416	9C	17C	17C	17C	3M	6M
15,000	625	17C	17C	17C	3M	6M	10M
20,000	833	17C	17C	3M	3M	6M	10M
25,000	1,040	17C	3M	3M	6M	10M	20M
30,000	1,250	17C	3M	3M	6M	10M	20M
40,000	1,656	3M	3M	6M	6M	20M	35M
50,000	2,080	3M	3M	6M	10M	20M	35M
100,000	4,160	6M	10M	10M	20M	35M	50M
150,000	6,250	10M	10M	20M	20M	50M	100M
200,000	8,330	10M	20M	20M	35M	75M	125M
250,000	10,410	20M	20M	20M	35M	75M	150M
300,000	12,500	20M	20M	35M	50M	100M	150M
400,000	16,660	20M	35M	35M	50M	125M	*200M
500,000	20,830	35M	35M	50M	75M	150M	*250M
600,000	25,000	35M	50M	50M	75M	*175M	*300M
800,000	33,330	50M	50M	75M	100M	*250M	.....
1,000,000	41,660	50M	75M	100M	125M	*300M	.....
1,500,000	62,500	75M	100M	125M	*200M	.....	.....
2,000,000	83,300	100M	125M	*200M	*275M	.....	.....

M=Thousands of Cubic Feet per hour.
C=Hundreds of Cubic Feet per hour.

*Use two or more meters in battery form.

AUTO GASOLINE COMPANY

Plant____________________

Gas Report on____________________ Farm____________

For Month of____________19___

Date	Meter Reading TODAY	Meter Reading YESTERDAY	GAS USED Meter Reading	Vacuum or Pressure	MULTI-PLIER	NET GAS USED at — oz. Base
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
31						
TOTALS						

COMPUTATION

(In duplicate form)

Gentlemen:

Attached hereto we hand you our check for $______in payment for Gas used on________ plant during month of__________as shown by above report.

AUTO GASOLINE COMPANY

*By*__________________

Fig. 53—MONTHLY STATEMENT BLANK SHOWING GAS PURCHASED FROM A LEASE

Table 71—METER CAPACITY REQUIRED FOR MEASURING GAS

Where the Gas is used to Generate Power either in a Gas Engine or Under Steam Boilers

Pressure Base 4 oz. Atmospheric Presure 14.4 lb. Static Pressure 4 oz.

Horse-power of Engine or Boilers	Capacity of Meter In Cu. Ft. per Hour		Horsepower of Engine or Boilers	Capacity of Meter In Cu. Ft. per Hour	
	For Gas Engine	For Steam Boiler		For Gas Engine	For Steam Boiler
10	500	800	150	3,000	10,000
15	500	1,500	200	6,000	20,000
20	800	1,500	300	6,000	20,000
25	800	3,000	400	10,000	35,000
35	1,500	3,000	500	10,000	35,000
50	1,500	6,000	600	10,000	50,000
75	3,000	6,000	800	20,000	50,000
100	3,000	10,000	1,000	20,000	75,000

To Read a Meter— In reading a meter the small or 100 foot dial should not be considered. Each sub-division in the circle represents one tenth of the figures placed above the circle. In other words, on the 10,000 dial, if the hand points between 7 and 8, the figure the hand has just passed (which would be 7) indicates that over 7,000 cubic feet have passed. The 1,000 foot dial is only taken into consideration when the hand points between 5 and 0, in which case it is counted as 1,000. In the foregoing case, if the hand on the 10,000 foot dial was close to 8 and the hand in the 1,000 foot dial pointed at 8 or 9, the reading of the 10,000 foot dial would be 8,000. Each dial above the 10,000 foot dial is read the same as the 10,000 foot dial above described.

In reading the dial no attention should be paid to the wording "one per cent" or "two per cent" printed on the face of the dial. This wording is intended for use when ordering new clock or tally, and has no bearing on the meter reading.

Recording Gauge—Where gas is measured at a greater pressure than four ounces, a recording gauge is necessary to determine the pressure throughout the 24 hours. From this pressure the multiplier for the average pressure can be ascertained and applied to the meter reading to obtain the actual amount of gas passed.

The recording gauge should be set on the meter itself and if it is a 24 hour gauge, the chart should be taken off daily and the day's reading, together with the previous day's reading, written on the back of the chart.

Before setting a recording gauge on a casinghead gas meter, see that the marking arm rests at zero.

It is very essential to have recording pressure gauges which are used in connection with large capacity meters tested, as an error of one pound would amount to from 6 to 7 per cent in the actual gas passed through the meter at 2 lb. pressure.

VOLUME AND PRESSURE RECORDING GAUGE

Seldom is casinghead gas sold in the field at atmospheric or 0 lb. pressure. Gases of any nature are compressible. It is not uncommon to measure casinghead gas at as low a pressure as 25 inches of mercury vacuum and natural gas at a pressure as high as 500 pounds. In buying or selling gas there is a recognized low pressure base. While this base varies from atmospheric pressure up to two or three pounds it is generally specified in the purchase agreement or contract.

All large capacity, casinghead gas or proportional meters are displacement meters and measure in cubic feet of "space" passing the meter, regardless of pressure, consequently meter readings must be reduced or corrected for the density at which the gas is measured. In doing this, tables of multipliers of various pressure bases will be found in "Measurement of Gas where Density Changes," published by this Company. For multipliers see pages 236 to 238.

Description—The Volume and Pressure Recording Gauge is a combination of a recording pressure gauge and a special meter index connected to a second pen arm. This second pen marks with a dash in the allotted space just outside of the pressure graduations on the chart, each 10,000 or 1,000 foot volume passing through the meter and is adapted for use on large capacity or proportional meters only.

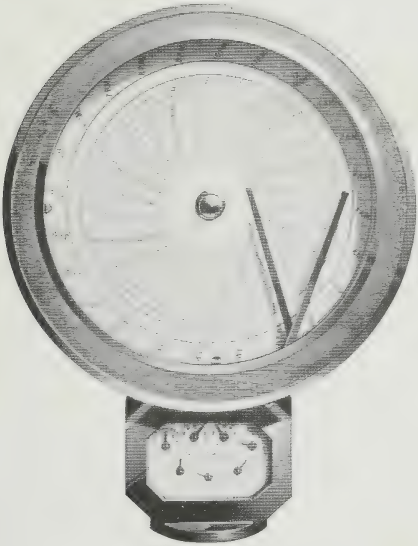


Fig. 54—VOLUME AND PRESSURE RECORDING GAUGE

Gauges for meters of 20,000 cubic feet per hour capacity are usually built with a 10,000 foot pen arm and gauges furnished for meters of smaller capacity are built with a 1,000 foot pen arm.

When in service on the gas line, if the volume of gas passing the meter is increased, the number of dashes per hour is increased and become shorter. On the other hand, if the volume of gas is decreased, the dashes become fewer and longer.

The back of the gauge carries a $\frac{1}{4}$ inch pressure connection which is connected with the tap in the tally cover.

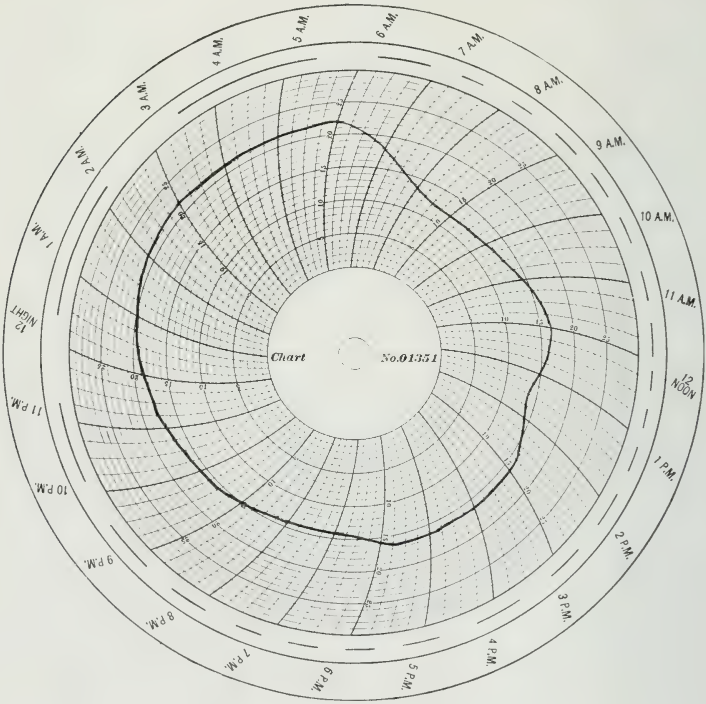


Fig. 55—VOLUME AND PRESSURE RECORDING GAUGE CHART. EACH DASH IN SPACE ADJOINING PRESSURE GRADUATIONS INDICATES A 10,000 CU. FT. VOLUME HAS PASSED THE METER

This device is of great assistance on lines working under vacuum. Whenever any leaks occur either at the casing-head or from breaks in the line, the air will naturally flow into the pipe line and the registration of the meter is greatly increased. Should any sudden break occur in the lines between the wells and the meter, the volume and pressure gauge will be of great assistance in determining when these leaks occurred as well as giving an approximation of the amount of air being taken into the lines.

It is practically impossible to discover leaks in a pipe line under vacuum unless one should happen to see the opening or break. They make no hissing noise such as is characteristic of leaks in a pipe line under pressure.

Another great advantage in this type of gauge is the fact that a record of the effect of pumping the oil wells can be determined by the assistance of the dashes on the gauge.

Invariably the pumping of a well will lower the oil level, thereby decreasing the resistance against the gas flowing from the sand into the well. This naturally increases the flow of gas and the chart will show at what time during the day the effect of the pumping was felt at the meter, as the majority of wells are only pumped a certain number of hours daily.

Reading the Volume and Pressure Gauge Chart—The simplest and most accurate way to read this chart is to divide each dash with a pencil mark, as shown in Fig. 56. Then follow the division mark on each dash along the graduation lines and mark the pressure line; in other words, one would be determining the pressure opposite one particular 10,000 ft. volume. Average the pressure between the two marks for each 10,000 ft. volume and find the multiplier in our book entitled "Measurement of Gases Where Density Changes." The multiplier can be written on the chart between the two dashes and after the process is followed out around the whole chart, the multipliers with the

decimal set to the right three places can be put on the adding machine and the volume quickly added for the 24 hour measurement, assuming that one is using the 24 hour chart, which is generally the case.

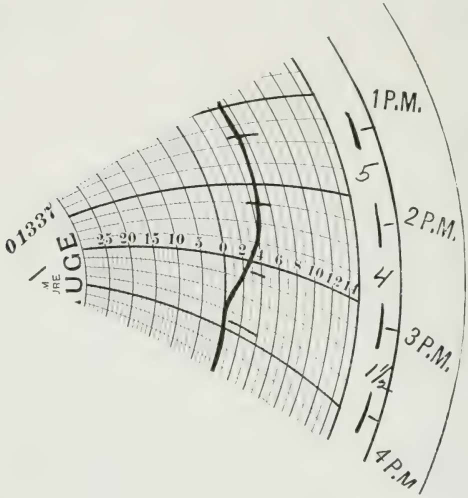


Fig. 56—SEGMENT OF A VOLUME AND PRESSURE CHART SHOWING PRESSURE RECORD, THE VOLUME RECORDED IN 10,000 FOOT DASHES AND PRESSURE AVERAGED OPPOSITE DASHES

Pressure	Volume	Multiplier	Low Pressure Gas Measured
5 lb.	10,000	1.3242	13,242
4 lb.	10,000	1.2559	12,559
1½ lb.	10,000	1.0853	10,853

Pressure Base=4 oz.

The amount of gas measured as indicated by the 10,000 ft. dashes can then be checked with the difference between the daily meter reading as taken by the index, and

reduced to low pressure by the common method of averaging the pressure for 24 hours and using one multiplier on the total meter reading for the same period. This however, is not absolutely necessary but can be used as a check method if desired.

It will be found in computing a series of these charts that invariably part of the last 10,000 ft. volume reduced will fall upon the following day's chart. In this case it will be necessary to take into consideration the pressure for that part of the 10,000 ft. volume that falls on the following day's chart, in consequence of which the actual amount of low pressure gas as figured by the dash method will check within 10,000 cu. ft. of the old method of using the planimeter on the 24 hour pressure chart and multiplying the meter reading by the multiplier for the average pressure as shown by the planimeter. This corrects itself from day to day. The reducing of meter readings, either under high pressure or at a vacuum, to a low pressure base with the assistance of the volume and pressure gauge, is more accurate than the old method of averaging the pressure for each 24 hours and then using one multiplier on the meter reading.

The volume marking arm of this gauge carries a flexible joint which can be bent one way or the other so that the dash will fall within the allotted space on the side of the chart. In shipping, sometimes the pen arm will become bent making the dash outside of the allotted space where it is more difficult to read and in addition might interfere with the pressure marking arm.

Proving Meters in the Field—In proving meters in the field use air or residue gas if possible. If gas is used take the specific gravity at least twice daily, even though working on one meter. The gravity of the residue gas will often run as high as 1.1 or higher, even after the gasoline has been extracted. This is due to the fact that some of the hydro-

carbons that have been extracted evaporate in the accumulator tank and pass out with the residue gas. The gravity of the residue gas will be highest in warm weather.

Greater caution should be used in proving with this gas, than with natural gas, as the residue gas, being so heavy, will hang near the ground and not rise. Do not run any tests within a building.

The error generally allowed in the field is 3 per cent fast or slow, while the factory is confined to a two per cent error either fast or slow.

Fig. 57—TESTING A CASINGHEAD GAS METER IN THE FIELD WHERE GAS IS UNDER A VACUUM.

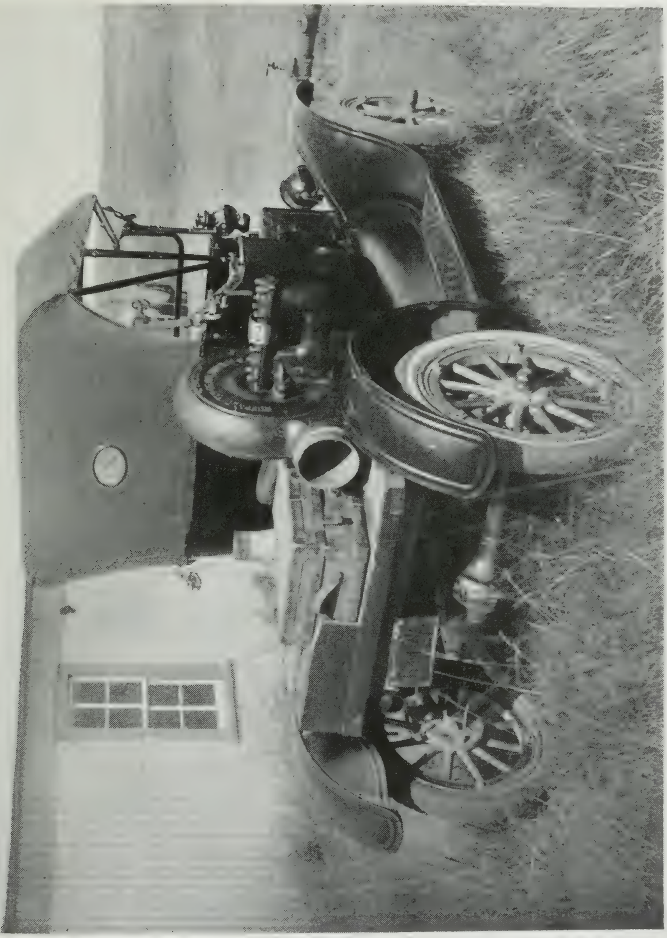


Fig. 58.—FIELD TESTING OUTFIT FOR CASINGHEAD GAS METERS. THIS METHOD IS QUITE NECESSARY WHERE METERS ARE MEASURING UNDER A VACUUM, AND IS A GREAT SAVER OF GAS WHEN THERE IS PLENTY OF IT AT A PRESSURE.

Air is Used Instead of Gas. Sufficient Volume and Pressure is Supplied by a Small Blower

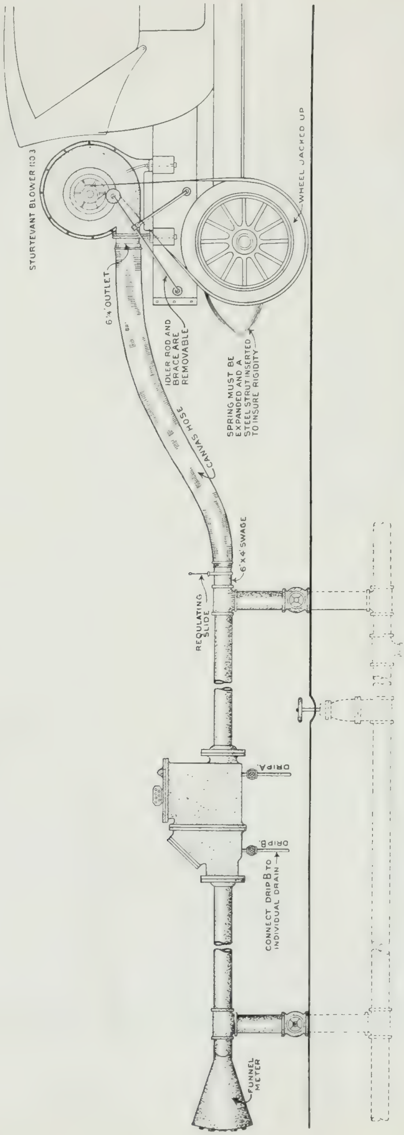


Fig. 59—PORTABLE METER-TESTING OUTFIT FOR USING AIR WHERE GAS UNDER PRESSURE IS UNOBTAINABLE

Invariably casinghead gas is measured by a meter under several inches vacuum. In order to test the meter residue gas or air under pressure must be used. As residue gas lines are not always near the meter location, the practical method to pursue is to test with air using a proving outfit installed on a Ford car, as shown in Fig. 59. Power is furnished by jacking one rear wheel off the ground and connecting the pulley on the blower to the wheel by a belt. The outlet of the blower is connected to the inlet of the meter by a canvas pipe. In determining the proper pressure to carry on the funnel it is not necessary to correct it for specific gravity.

For the past three or four years several large gasoline companies in Oklahoma have been making it a practice to remove the tallies from their casinghead gas meters, repairing and testing them in a meter-proving room at the plant and after reinstalling them would invariably find the meter within two per cent of being correct. They carried a few extra tallies which were kept in perfect condition, and as soon as an old tally was removed from the meter one of the tallies from stock was substituted, keeping the meter out of service for only a short period. No filing or soldering on the proportional valve was found necessary, the meter was very carefully cleaned, and all bearing points properly oiled and the parts in the main body of the meter were not otherwise changed. The writer has carefully watched the results of the above method for the past two or three years and does not hesitate to suggest that other companies follow the same method.

If meters are used in a pipe line in which there is pulsation or vibration in the gas, the above statement would not apply, as there would have to be some soldering done on the under part of the proportional valve to offset the wear due to the pulsation.

Funnel Meter—While it is true that the funnel meter is a simple instrument, yet in order to obtain reliable results with it, it is very essential that the operator should be experienced in the use of the instrument and at the same time have a thorough knowledge of how to repair and correct the meter being tested. The proper place to gain this experience is at the factory. The most successful combination to make a large capacity meter expert is the actual experience in the field combined with experience of large capacity meter testing derived in the factory.

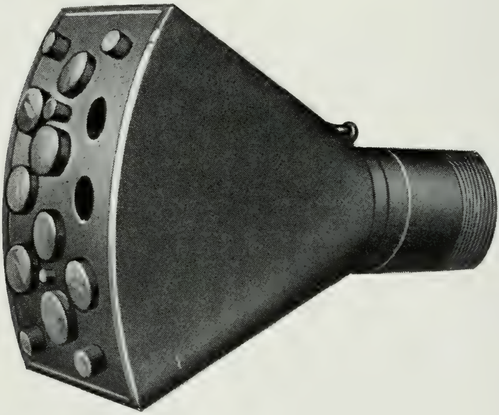


Fig. 60—FUNNEL METER FOR PROVING METERS IN THE FIELD

Great care should be used, not only in handling, but in storing the funnel meter when not in use. The edge of the different orifices should be kept perfectly dry. Rusting of the edges of the orifices will create inaccuracy in testing, and should this occur, the funnel meter should be repaired and re-tested at the factory. In case the head—carrying the orifices—becomes dented, it is also necessary to have the funnel meter tested.

Funnel Meter Testing Pressure—To determine the correct pressure of the gas flowing through the funnel meter orifices while testing meters it is necessary to take into consideration the temperature of the flowing gas, the barometer reading and the specific gravity of the gas used. The formula for same is as follows:

$$\frac{BG}{.0138\ (t+460)} = P_f$$

In which

B = Barometer reading in inches of mercury.
t = Temperature of flowing gas in deg. fahr.
G = Specific Gravity of gas used.
P_f = Pressure in inches of water to be carried on gas flowing through funnel meter orifices.

In the above formula 460 is the absolute temperature below zero, and .0138 is the constant determined by actual tests. The table found on pages 255 and 256 is worked out by the following formula:

$$\frac{B}{.0138\ (t+460)} = P_f$$

in which P_f equals the pressure to be used when testing with air. In using the tables on pages 255 and 256 in testing with gas it is necessary to multiply the correct pressure in the table by the specific gravity of the gas.

In proving it is necessary to use a common six inch or larger siphon gauge connected by rubber tubing to the nipple found in one of the rubber plugs accompanying the funnel. This rubber plug should be inserted in one of the orifices on the face of the funnel. Fill the siphon gauge until the water level reaches the zero mark. When the rubber plug with the small nipple is connected with the siphon gauge, it will show the gas pressure on the face of the funnel meter.

After the funnel has been properly attached to the meter, either into a tee in the pipe line between the outlet flange and the gate ahead of the meter, or by screwing it directly into the end flange bolted to outlet of meter, the gas should be turned on very slowly, especially if the pressure behind the inlet gate is high, and the meter allowed to run for a few moments prior to starting the actual test. During this period, an inspection of the joints or connections should be made, between the funnel and the inlet of the meter. Even though the pressure carried through the meter is very low, small leaks ahead of the meter will have considerable bearing upon a true test. Soap suds and a large brush can be used to advantage. Leaks on the inlet to the meter will have no effect on the test.

The meter should be proved from a small volume up to and just above its maximum capacity. For instance, if it is a 20,000 foot meter, test should begin at 3,600 feet per hour, or with one 1½ inch hole open, and up to 21,600 feet per hour, or six 1½ inch holes open. In proving this size meter, tests should be made with two, three, four, five and six holes open.

Use water in the siphon gauge, filling it to the zero mark in center of the scale.

After the funnel has been set or installed, and the gas turned on, the temperature of the flowing gas through the funnel should be taken, and the barometer reading observed, to assist in determining the proper pressure to carry.

To determine the proper pressure to carry on the funnel after noting the barometer, thermometer reading and specific gravity of the gas, see table on pages 255 and 256, and select the pressure corresponding to your thermometer reading in the proper barometer column. The pressure shown in the

Table 72—FUNNEL METER TESTING PRESSURES

Using Air of various Barometric Pressures and Temperatures in Testing Casinghead Gas Meters

Deg. fahr.	Barometer Reading Inches of Mercury														
	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9	30.0
	Pressure in Inches of Water														
30	4.23	4.24	4.26	4.27	4.29	4.30	4.32	4.33	4.35	4.36	4.38	4.39	4.40	4.42	4.44
31	4.22	4.24	4.25	4.27	4.28	4.29	4.31	4.32	4.34	4.35	4.37	4.38	4.39	4.41	4.43
32	4.21	4.23	4.24	4.26	4.27	4.29	4.30	4.32	4.33	4.34	4.36	4.37	4.39	4.40	4.42
33	4.20	4.22	4.23	4.25	4.26	4.28	4.29	4.31	4.32	4.34	4.35	4.37	4.38	4.39	4.41
34	4.20	4.21	4.22	4.24	4.25	4.27	4.28	4.30	4.31	4.33	4.34	4.36	4.37	4.39	4.40
35	4.19	4.20	4.22	4.23	4.25	4.26	4.27	4.29	4.30	4.32	4.33	4.35	4.36	4.38	4.39
36	4.18	4.19	4.21	4.23	4.24	4.25	4.27	4.28	4.30	4.31	4.32	4.34	4.35	4.37	4.38
37	4.17	4.18	4.20	4.21	4.23	4.24	4.26	4.27	4.29	4.30	4.32	4.33	4.34	4.36	4.37
38	4.16	4.17	4.19	4.21	4.22	4.23	4.25	4.26	4.28	4.29	4.31	4.32	4.34	4.35	4.37
39	4.15	4.17	4.18	4.20	4.21	4.23	4.24	4.25	4.27	4.28	4.30	4.31	4.33	4.34	4.36
40	4.14	4.15	4.17	4.19	4.20	4.22	4.23	4.25	4.26	4.28	4.29	4.30	4.32	4.33	4.35
41	4.14	4.15	4.17	4.18	4.19	4.21	4.22	4.24	4.25	4.27	4.28	4.29	4.31	4.32	4.34
42	4.13	4.14	4.16	4.17	4.19	4.20	4.22	4.23	4.24	4.26	4.27	4.29	4.30	4.32	4.33
43	4.12	4.12	4.15	4.16	4.18	4.19	4.21	4.22	4.24	4.25	4.26	4.28	4.29	4.31	4.32
44	4.11	4.13	4.14	4.16	4.17	4.18	4.20	4.21	4.23	4.24	4.26	4.27	4.28	4.30	4.31
45	4.10	4.12	4.13	4.15	4.16	4.18	4.19	4.20	4.22	4.23	4.25	4.26	4.28	4.29	4.30
46	4.10	4.11	4.12	4.14	4.15	4.17	4.18	4.20	4.21	4.23	4.24	4.25	4.27	4.28	4.30
47	4.09	4.10	4.12	4.13	4.14	4.16	4.17	4.19	4.20	4.22	4.23	4.24	4.26	4.27	4.29
48	4.08	4.09	4.11	4.12	4.14	4.15	4.17	4.18	4.19	4.21	4.22	4.24	4.25	4.27	4.28
49	4.07	4.09	4.10	4.11	4.13	4.14	4.16	4.17	4.19	4.20	4.21	4.23	4.24	4.26	4.27
50	4.06	4.08	4.09	4.11	4.12	4.13	4.15	4.16	4.18	4.19	4.20	4.22	4.23	4.25	4.26
51	4.06	4.07	4.08	4.10	4.11	4.13	4.14	4.15	4.17	4.18	4.20	4.21	4.23	4.24	4.25
52	4.05	4.06	4.08	4.09	4.10	4.12	4.13	4.15	4.16	4.18	4.19	4.20	4.22	4.23	4.25
53	4.04	4.05	4.07	4.08	4.10	4.11	4.12	4.14	4.15	4.17	4.18	4.20	4.21	4.22	4.24
54	4.03	4.05	4.06	4.07	4.09	4.10	4.12	4.13	4.14	4.16	4.17	4.19	4.20	4.21	4.22
55	4.02	4.04	4.05	4.07	4.08	4.09	4.11	4.12	4.14	4.15	4.17	4.18	4.19	4.21	4.22
56	4.02	4.03	4.04	4.06	4.07	4.09	4.10	4.11	4.13	4.14	4.16	4.17	4.19	4.20	4.21
57	4.01	4.02	4.04	4.05	4.06	4.08	4.09	4.11	4.12	4.13	4.15	4.16	4.18	4.19	4.20
58	4.00	4.01	4.03	4.04	4.06	4.07	4.09	4.10	4.11	4.13	4.14	4.15	4.17	4.18	4.20
59	4.00	4.01	4.02	4.04	4.05	4.06	4.08	4.09	4.10	4.12	4.13	4.15	4.16	4.17	4.19
60	3.99	4.01	4.02	4.03	4.04	4.06	4.07	4.08	4.10	4.12	4.13	4.14	4.16	4.17	4.18
61	3.98	4.00	4.01	4.02	4.04	4.06	4.07	4.08	4.10	4.11	4.12	4.14	4.15	4.16	4.17
62	3.97	3.99	4.00	4.02	4.03	4.04	4.06	4.07	4.08	4.10	4.11	4.13	4.14	4.15	4.16
63	3.97	3.98	3.99	4.00	4.02	4.04	4.05	4.06	4.08	4.09	4.11	4.12	4.14	4.15	4.16
64	3.96	3.97	3.99	4.00	4.01	4.03	4.04	4.06	4.07	4.09	4.10	4.11	4.12	4.14	4.15
65	3.95	3.96	3.98	3.99	4.01	4.02	4.04	4.05	4.06	4.08	4.09	4.10	4.12	4.13	4.15
66	3.94	3.96	3.97	3.99	4.00	4.01	4.03	4.04	4.05	4.07	4.08	4.09	4.10	4.11	4.13
67	3.93	3.95	3.96	3.98	3.99	4.00	4.02	4.03	4.05	4.07	4.08	4.09	4.10	4.11	4.12
68	3.93	3.94	3.96	3.97	3.98	4.00	4.01	4.03	4.04	4.05	4.07	4.08	4.09	4.11	4.12
69	3.92	3.93	3.95	3.96	3.98	3.99	4.00	4.02	4.03	4.05	4.06	4.07	4.09	4.10	4.11

Note—When using gas in testing with Funnel Meter, multiply above Pressures by the Specific Gravity of the Gas.

Table 73—FUNNEL METER TESTING PRESSURES

Using Air of various Barometric Pressures and Temperatures in Testing Casinghead Gas Meters

Deg. fahr.	Barometer Reading Inches of Mercury														
	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9	30.0
	Pressure in Inches of Water														
70	3.91	3.92	3.94	3.96	3.97	3.98	4.00	4.01	4.02	4.04	4.06	4.07	4.07	4.08	4.10
71	3.91	3.92	3.94	3.95	3.96	3.98	3.99	4.00	4.02	4.03	4.05	4.05	4.05	4.07	4.09
72	3.91	3.91	3.93	3.94	3.96	3.97	3.99	4.00	4.01	4.01	4.02	4.03	4.05	4.06	4.08
73	3.90	3.91	3.92	3.94	3.95	3.96	3.98	3.99	4.00	4.01	4.02	4.03	4.05	4.06	4.08
74	3.90	3.90	3.91	3.93	3.94	3.96	3.97	3.98	4.00	4.01	4.02	4.03	4.06	4.06	4.07
75	3.88	3.90	3.90	3.92	3.93	3.95	3.96	2.97	3.98	4.00	4.02	4.03	4.03	4.04	4.06
76	3.87	3.88	3.89	3.90	3.93	3.94	3.95	3.96	3.97	4.00	4.01	4.01	4.02	4.04	4.06
77	3.86	3.88	3.89	3.90	3.92	3.93	3.95	3.96	3.97	3.99	4.01	4.01	4.03	4.04	4.06
78	3.86	3.87	3.88	3.89	3.91	3.92	3.94	3.95	3.97	3.98	3.99	4.01	4.02	4.03	4.05
79	3.85	3.86	3.88	3.89	3.90	3.92	3.93	3.94	3.96	3.97	3.98	4.00	4.01	4.02	4.04
80	3.84	3.85	3.87	3.89	3.90	3.91	3.92	3.94	3.95	3.96	3.98	3.99	4.00	4.01	4.03
81	3.84	3.85	3.86	3.88	3.89	3.90	3.91	3.93	3.94	3.96	3.98	3.99	4.00	4.01	4.02
82	3.83	3.84	3.85	3.87	3.88	3.90	3.92	3.93	3.94	3.96	3.98	3.99	4.00	4.00	4.01
83	3.82	3.84	3.85	3.86	3.88	3.89	3.90	3.91	3.93	3.94	3.96	3.97	3.98	3.99	4.00
84	3.82	3.83	3.85	3.86	3.86	3.89	3.90	3.91	3.93	3.94	3.96	3.97	3.97	3.99	4.00
85	3.81	3.82	3.84	3.85	3.86	3.88	3.88	3.90	3.91	3.92	3.94	3.95	3.96	3.98	3.99
86	3.80	3.81	3.83	3.84	3.85	3.87	3.88	3.89	3.90	3.92	3.93	3.95	3.96	3.97	3.99
87	3.80	3.80	3.82	3.83	3.84	3.86	3.87	3.88	3.89	3.90	3.92	3.94	3.95	3.97	3.98
88	3.79	3.80	3.81	3.83	3.84	3.85	3.87	3.88	3.89	3.90	3.91	3.93	3.95	3.96	3.97
89	3.78	3.80	3.81	3.82	3.84	3.84	3.86	3.87	3.88	3.89	3.91	3.92	3.94	3.95	3.97
90	3.77	3.79	3.80	3.82	3.83	3.84	3.85	3.86	3.87	3.88	3.90	3.91	3.93	3.95	3.96
91	3.76	3.78	3.80	3.81	3.83	3.84	3.84	3.86	3.87	3.88	3.90	3.91	3.92	3.94	3.96
92	3.76	3.77	3.79	3.81	3.82	3.82	3.83	3.85	3.86	3.87	3.89	3.90	3.91	3.93	3.94
93	3.75	3.76	3.78	3.79	3.80	3.82	3.83	3.84	3.86	3.87	3.88	3.89	3.90	3.92	3.93
94	3.75	3.76	3.77	3.78	3.79	3.81	3.82	3.84	3.85	3.86	3.87	3.88	3.90	3.91	3.92
95	3.74	3.75	3.76	3.78	3.79	3.81	3.82	3.83	3.84	3.85	3.86	3.88	3.89	3.91	3.92
96	3.74	3.75	3.76	3.77	3.78	3.80	3.81	3.82	3.84	3.86	3.86	3.87	3.88	3.90	3.91
97	3.73	3.74	3.75	3.77	3.78	3.79	3.80	3.82	3.84	3.85	3.87	3.87	3.89	3.89	3.90
98	3.72	3.74	3.75	3.76	3.77	3.78	3.80	3.81	3.82	3.83	3.85	3.86	3.87	3.88	3.90
99	3.71	3.73	3.73	3.75	3.77	3.78	3.79	3.80	3.81	3.83	3.84	3.86	3.87	3.88	3.89
100	3.71	3.72	3.72	3.74	3.76	3.77	3.78	3.79	3.80	3.82	3.83	3.85	3.86	3.87	3.88
101	3.70	3.71	3.72	3.74	3.75	3.76	3.77	3.79	3.80	3.81	3.83	3.84	3.85	3.86	3.88
102	3.69	3.70	3.71	3.73	3.74	3.75	3.76	3.78	3.79	3.81	3.82	3.83	3.84	3.85	3.87
103	3.68	3.70	3.71	3.72	3.74	3.75	3.76	3.77	3.79	3.80	3.81	3.83	3.84	3.85	3.87
104	3.67	3.69	3.70	3.71	3.72	3.74	3.75	3.76	3.78	3.79	3.80	3.81	3.83	3.84	3.86
105	3.67	3.68	3.70	3.71	3.72	3.73	3.74	3.76	3.77	3.79	3.80	3.81	3.83	3.84	3.85
106	3.66	3.68	3.69	3.70	3.72	3.73	3.74	3.76	3.77	3.78	3.79	3.80	3.82	3.83	3.84
107	3.66	3.68	3.68	3.70	3.71	3.72	3.72	3.75	3.76	3.78	3.79	3.80	3.81	3.83	3.84
108	3.65	3.67	3.68	3.69	3.70	3.72	3.73	3.74	3.75	3.77	3.78	3.79	3.80	3.82	3.83

NOTE—When using gas in testing with Funnel Meter, multiply above Pressures by the Specific Gravity of the Gas.

table is the proper pressure to carry when proving with a funnel using air. In proving with any gas, multiply the pressure found in the table by the specific gravity of the gas.

In reading the siphon gauge, read both sides of the scale, which added together will give the pressure being carried.

If the pressure figures out 2.4 inches, this pressure should be carried throughout the entire test, regardless of the number of holes open in the face of the funnel. Great care should be used to note that the pressure remains constant during each individual test, otherwise a true test of the meter cannot be obtained.

Time of Tests—Each 1½ inch orifice will pass 3,600 cubic feet per hour or 100 cubic feet in 100 seconds. If two holes are open they will pass twice as much in one hour or 7,200 cubic feet. Increasing the number of open holes increases the flow proportionately. There being 3600 seconds in an hour,and each 1½ inch hole passing 3600 cubic feet per hour, in running a 100 foot test, each second over or under 100 seconds will mean 1 per cent. For instance, if with one hole open, the meter records 100 feet on the dial in 98 seconds by the stop watch, the meter is 2 per cent fast. If the meter records 100 feet in 102 seconds, the meter is 2 per cent slow. The exception to the above percentage rule is where a meter is running fast and the time is 90 seconds or less. Employ regular percentage rule to determine the per cent fast when the percentage figures are to be used to make a correction in the meter bill for any previous length of time. As far as the mechanical work in correcting the meter is concerned, one second for one per cent can be used, even though the meter records 100 feet in 50 seconds when tested.

The following is a table of the different capacities of the funnel meter at proper pressure, where a test is made in using the 100 foot dial, and also in using the 1,000 foot dial.

Table 74—FUNNEL METER PROVING PERIODS

Holes open	Volume per hour	Time of test with 100 ft. dial Sec.	Volume passed meter in proving with 100 ft. dial Feet	Time of test with 1000 ft. dial Min.	Sec.	Volume passed meter in proving with 1000 ft. dial Feet
1	3,600	100	100	16	40	1,000
2	7,200	100	200	8	20	1,000
3	10,800	100	300	5	33	1,000
4	14,400	100	400	4	10	1,000
5	18,000	100	500	3	20	1,000
6	21,600	100	600	2	46	1,000
8	28,800	100	800	2	5	1,000
10	36,000	100	1,000		100	1,000
12	43,200	100	1,200		100	1,200
14	50,400	100	1,400		100	1,400
16	57,600	100	1,600		100	1,600
18	64,800	100	1,800		100	1,800
20	72,000	100	2,000		100	2,000

Specific Gravity——In testing casinghead gas meters with air, no correction is made on the pressure as selected from the table on pages 255 and 256. In testing with residue gas it is necessary to take the gravity of the gas at least twice a day during the test. Ordinarily, if the meter is in good condition and has been tested within the previous 60 days, the test would require but one or two hours, and one test of the gravity is all that would be necessary.

It must be understood that casinghead gas will change its gravity more often than residue gas. In fact, it will change its gravity with a change in weather. A cool, cloudy day will give a lighter gravity of gas than an extremely warm day. The cooler the day the greater the condensation of the gasoline vapor in the pipe line. This constantly changing gravity of the gas is not only due to the change in the weather but to the construction of the pipe line whether exposed to the atmosphere or not.

Table 75—CORRECTING FACTORS FOR FAST (+) AND SLOW (—) LARGE CAPACITY METERS

Based on a 1½ inch Orifice passing 100 Cubic Feet in 100 seconds at Four Inches Water Pressure, corrected for Barometer and Temperature and Specific Gravity of Gas used in testing.

Fast Meters			Slow Meters		
Time Required by Meter to Register 100 Cu. Ft. in Seconds	Per Cent Fast (Funnel Meter being Standard)	Correcting Factor. Deduct Meter Reading Per Cent	Time Required by Meter to Register 100 Cu. Ft. in Seconds	Per Cent Slow (Funnel Meter being Standard)	Correcting Factor. Add to Meter Reading Per Cent
100	O. K.	none	100	O. K.	none
99	1 +	1	101	.9—	1
98	2 +	2	102	1.9—	2
97	3 +	3	103	2.9—	3
96	4.1+	4	104	3.8—	4
95	5.2+	5	105	4.7—	5
94	6.3+	6	106	5.6—	6
93	7.5+	7	107	6.5—	7
92	8.6+	8	108	7.4—	8
91	9.8+	9	109	8.2—	9
90	11.1+	10	110	9. —	10
89	12.3+	11	111	9.9—	11
88	13.6+	12	112	10.7—	12
87	14.9+	13	113	11.5—	13
86	16.2+	14	114	12.2—	14
85	17.6+	15	115	13. —	15
84	19. +	16	116	13.7—	16
83	20.4+	17	117	14.5—	17
82	21.9+	18	118	15.2—	18
81	23.4+	19	119	15.9—	19
80	25. +	20	120	16.6—	20
79	26.5+	21	121	17.3—	21
78	28.1+	22	122	18. —	22
77	29.8+	23	123	18.6—	23
76	31.5+	24	124	19.3—	24
75	33.3+	25	125	20. —	25
74	35.1+	26	126	20.6—	26
73	36.9+	27	127	21.2—	27
72	38.8+	28	128	21.8—	28

Example—If a meter passes 100 cubic feet in 80 seconds the meter is 25 per cent fast on a basis of the funnel being standard but the correcting factor being 20, to correct meter reading, deduct 20 per cent.

Date........................19....

Owner..

....

On.......................lease.

No............ Capacity.......................M. 50 Pounds Test

Tally No.....................

Flange............ Reading after test............Cu. Ft.

" before " .... " "

Measuring at............per hour. Used............ " "

Specific gravity of gas..............

Change Wheel.......... Drive Wheel.......... Chart No........

Funnel Meter Test			Data
Volume per Hour	Preliminary Test	Final Test	Sp. Grav. of Gas
Cu. ft.	%	%	Barometer
			Temperature
900			Press. on Funnel
1,800			Tested with
2,700			Air
3,600			Residue
7,200			Casinghead Gas
10,800			Remarks
14,400			
18,000			
21,600			
28,800			
36,000			
43,200			
50,400			
57,600			
64,800			
72,000			
90,000			
108,000			

Witnessed by

....

Date.............................. Inspector

Fig. 61—METER PROVING REPORT

Siphon or "U" Gauges—These are the most convenient low pressure gauges in use, being portable and simply screwed to the piping wherever it is desired to take the pressure.

They consist of a U-shaped glass tube with a metal goose-neck, in sizes from 4 inch to 36 inch. Between the two sides or legs of this tube is set a scale graduated in inches and tenths, or pounds and ounces, as desired. A bent brass tube, or goose-neck, is connected to the "U" tube at the top and runs down the side to the gas connection.

When used the gauge is filled with water or mercury to the center of the scale, which is zero. The gauge is connected to the gas supply and the pressure turned on. The liquid will fall below zero on the inlet side of the "U" tube and rise on the opposite side the same distance. The distance between the two levels of the liquid as shown by the scale will give the amount of pressure in inches and tenths or in pounds and ounces, according to the graduation.

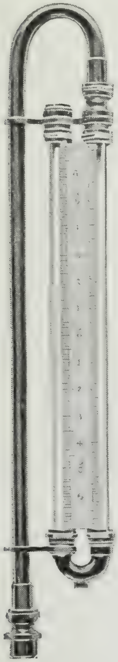


Fig. 62—SIPHON OR "U" GAUGE

While the gauge is in use the downward motion of the liquid in one column, due to the pressure of the gas, should equal the rise of liquid in the opposite column. In case the water, after being set at zero, should not drop on the pressure side as much as it rises on the other side, it is an indication that the glass tubes are not of equal diameter, and both columns must be read, their sum being the true pressure.

Water is generally used in siphon gauges in testing domestic meters and measuring small gas wells. It is also used in testing large capacity meters in the field.

Portable Blower—The most satisfactory gas to use in testing meters is air, using a portable blower attached on the rear of an automobile and belted to the rear wheel of the auto. when it is jacked up.

With this outfit one is absolutely independent of the variations in the gravity of the gas and can obtain far greater accuracy than with casinghead or residue gas with their ever varying gravity.

MEASURING CASINGHEAD GAS BY ORIFICE METER

While the orifice meter is mainly used for the measurement of natural gas at high pressure it also can be used for the measurement of casinghead gas. Natural gas invariably has a very constant gravity but casinghead gas has a constantly changing gravity which with the extremely low pressure at which it measured, presents difficulties in its measurement by orifice meter that are not found in the measurement of natural gas. The writer has always advocated the use of the displacement meter, sometimes called proportional meter, for measuring casinghead gas, as the general results obtained were above what might have been obtained by the orifice meter. However, there are instances where companies have employees trained for the care and reading of the orifice meter, who without doubt, will meet with success by using this instrument. If one intends to measure casinghead gas with orifice meters the following points should be carefully considered while they are not objections when properly treated or handled, they will cause failures unless understood and precautionary measures taken.

It is well known that casinghead gas in gathering lines is generally under a vacuum. This vacuum is attained by the use of pumps and in other words, the absolute pressure is artificial, not a natural rock pressure as found in natural gas. To create this artificial pressure considerable investment is required.

Fig. 63—10 INCH RECORDING DIFFERENTIAL AND STATIC PRESSURE GAUGE

Absorption of Pressure—Whenever an orifice is placed in a line a loss of pressure is created. This loss varies from 40 to 100 per cent of the differential reading on the chart. For instance if the differential reading were 56 inches the loss in pressure would be not less than 13 ounces and may amount to 2 pounds through the orifice depending on the location of the pressure connections and the size of orifice. As the size of the orifice increases the proportion of pressure loss due to friction compared to differential reading becomes less. For smaller sizes of orifices the lost head is equal or nearly equal to the differential pressure. On a vacuum line this loss tends to create a less vacuum if the meter is placed between the pump and the well. Each 13.6 inches of water pressure amounts to 1 inch of mercury vacuum. For example, if a vacuum pump pulling 26 inches of vacuum is placed on a line and the normal pressure loss through the line without an orifice is 2 pounds or approximately 4 inches of mercury head, the vacuum at the well would be 22 inches. If an orifice is placed in this line and the differential gauge reading is 56 inches of water pressure (approximately 4 inches of mercury head) then the vacuum existing at the well is only 18 inches. In this case it will be noted that the orifice creates as much friction loss as the pipe line itself.

To overcome this difficulty differential gauges having a maximum reading of 10 inches and of 20 inches have been placed on the market. By using meters of these lower ranges the size of the orifice is increased, thereby decreasing the total differential pressure required to obtain an accurate reading, and also the proportionate friction loss as compared with the differential reading.

The use of orifice meters having a differential range of from 60 to 100 inches on vacuum lines should be discouraged on account of the friction losses above stated. Any differential gauge having a range from 0 to 10 inches or greater, will have capacity enough to measure the flow through any

vacuum line. The maximum capacity of a 10 inch differential gauge is 33 per cent of the maximum capacity of a 100 inch gauge and 71 per cent of the maximum capacity of the 20 inch gauge. However, the friction loss in measuring the same quantity of gas at same relative reading on the 10 inch differential gauge chart would be less than 10 per cent of 100 inch gauge and less than 50 per cent of that for a 20 inch gauge. For instance in the previous example with a 10 inch gauge chart reading the friction loss would be less than 5.6 inches of water pressure or 0.4 inches of mercury head which would leave a vacuum of 21.6 inches at the well with 26 inches at the pump and a line loss of 4 inches mercury head. Although it is possible to obtain low readings from differential gauges having the higher ranges the percentage of accuracy in reading cannot be obtained, as when using gauges of lower maximum ranges. For instance, the closest reasonable reading which could be obtained in a 100 inch chart is about ½ of an inch. The error for a 2 inch differential reading will amount to 12 per cent, whereas, on a 10 inch chart it is easily possible to obtain readings within .05 inch, which would amount to 1¼ per cent deviation for a 2 inch differential reading.

Capacity Limits—The limits between the maximum and minimum capacities of orifice meters are necessarily small. The minimum capacity for accurate readings being about one-fourth of the maximum capacity. For instance if an orifice meter with a certain size orifice at constant pressure has a maximum capacity of 100,000 cu. ft. per day, the minimum capacity of this orifice would be approximately 25,000 cu. ft. per day. Comparing this meter with a displacement meter whose minimum range is approximately 1-20th of the maximum range the displacement meter has approximately five times as much range as the orifice meter without any change or substitution in the size of the meter. While it is true that the orifice can be changed, it is a disadvantage when

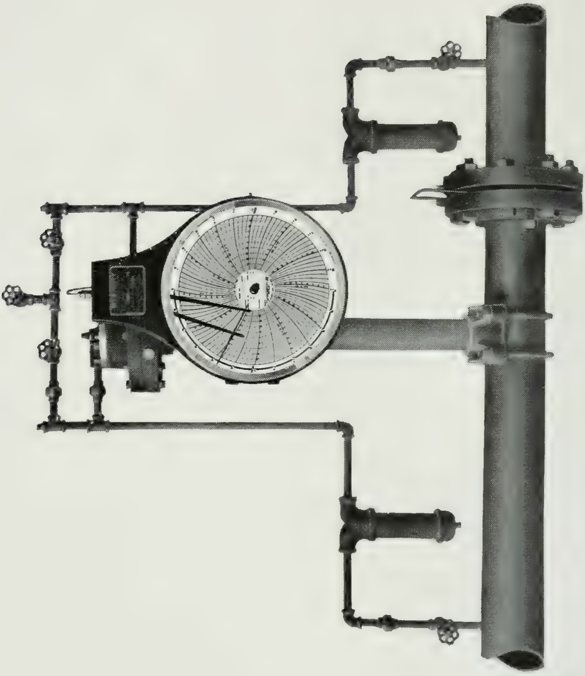


Fig. 64—ORIFICE METER AND 20 INCH DIFFERENTIAL GAUGE INSTALLATION

measuring a volume of gas which varies from small load to a high load within 24 hours. Differential pressure regulators have been installed with a battery of orifice meters which automatically transfer the flow through one orifice meter to two or more orifice meters in parallel when the volume increases and reduce the number of meters in operation when the volume decreases.

Pulsation—Orifice meters are more easily affected by pulsation in the flowing gas, than displacement meters, in other words, they are more sensitive. Care in regard to pulsation must be used in selecting a place for installation on the pipe line. Many companies will attempt to use washers carrying pin holes in half unions, one on either side of the gauge, or two deadeners in order to kill the pulsating effects upon the gauge. The deadener, which is also used to kill the pulsation, simply consists of a joint of pipe connected in a gauge line, one installation calling for two deadeners, one on either gauge line. The standing volume of gas in the deadener acts as a cushion on the pulsation from the pipe line and greatly assists in steadying the differential line on the chart. These deadeners or washers with pin holes, give the appearance on the chart of being very successful but after the installation of the foregoing one has done nothing to overcome the effects of pulsation on the orifice in the pipe line. It is just as necessary to have a steady flowing volume of gas through the orifices as it is to have a steady marked line on the chart. There is no set rule to go by that the writer knows of in regard to when and when not to install these meters where the gas is pulsating. It might be said that in any installation where the static pressure pen arm does not vibrate that the resultant reading obtained will be correct. It is certain that if the static pen arm does vibrate that the reading obtained will be in error, probably as much as 50 per cent.

Differential gauges equipped with pulsation bushings or small bushings which retard the flow of mercury from the high pressure portion of the gauge to the low pressure portion of the gauge, or vice versa, automatically average the peaks and hollows of the differential reading, in cases of wells which flow by heads or where a well is supplying fuel to a drilling boiler or any machine which consumption of fuel is intermittent. Bushings installed in the mercury columns do not decrease the accuracy of the gauge except where the movement of the differential pen arm is greatly retarded requiring more than three minutes to cover the range of the chart or where the static pen arm vibrates. Deadeners should never be placed in the gauge lines as they may become partially stopped up and actually prevent the full pressure at the connection from being exerted on the mercury. Pulsation bushings will not produce an accurate reading even though the recorded differential line is a smooth line when the static pressure varies rapidly for the reason that sufficient time may not elapse between the periods of increased pressure or decreased pressure for the differential pen arm to assume a mean reading, the reading being erroneous due to the number of impacts occasioned by the intermittent delivery or consumption of the gas. There is only one way to take care of a situation of this kind and that is to place a deadener or reservoir in a main gas line large enough to absorb the shocks and cause a steady flow from the deadener or reservoir.

Where orifice meters are placed on field lines, drips should be placed at all low points between the orifice meter and the well and the drips should receive proper attention so that the line would not become sealed by free gasoline or any other liquid in the sags or low places. When this does occur the gas will not flow through the liquid seal steadily, but will flow by the heads. This in turn will create a pulsation which interferes with the accuracy of the orifice meter.

Effects of Specific Gravity Upon Orifice Meter Readings—The coefficient for the orifice used must be corrected to the specific gravity of the gas. In casinghead gas where the gravity varies constantly the only method possible is to average the specific gravity. This should be done weekly or monthly and the coefficient corrected.

Unlike natural gas, casinghead gas is extremely heavy. The heavier the gas, which is practically composed of vapors,

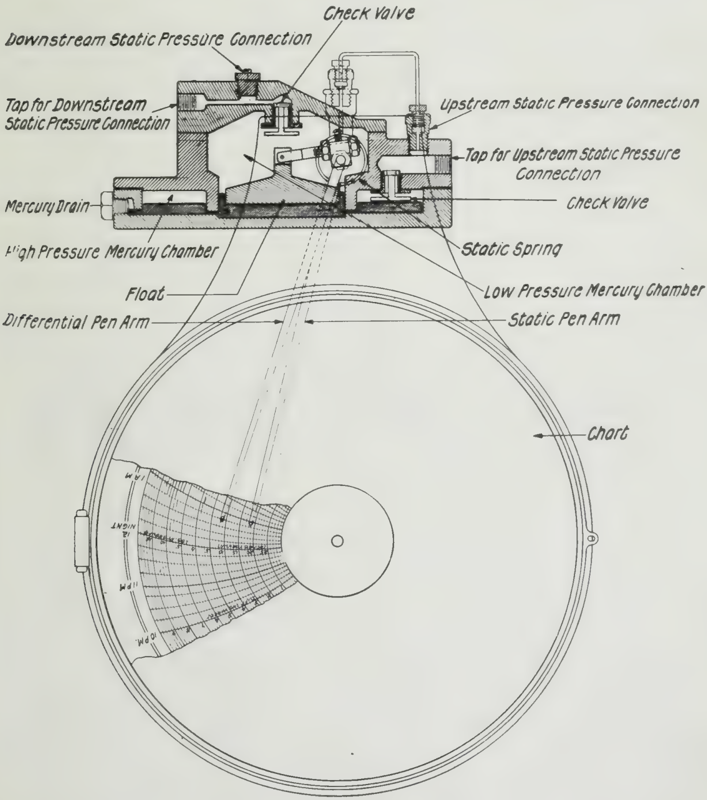


Fig. 65—DIFFERENTIAL AND STATIC PRESSURE GAUGE RANGE 0 TO 10 IN.

the greater the change in gravity due to changes in the temperature. Cold weather will give a light gravity and warm weather a heavy gravity. A cold day a light gravity, and a sunshiny day a heavy gravity. In the night time the gas is lighter than it is in the day time. Any change of temperature whatsoever the cause, will have its effect upon the specific gravity of the gas.

In addition to the foregoing, the orifice meter gauge is subject to error and derangement just the same as the displacement or proportional meter. This subject is very carefully covered in the Hand Book entitled "Measurement of Gas by Orifice Meter," published by the Metric Metal Works.

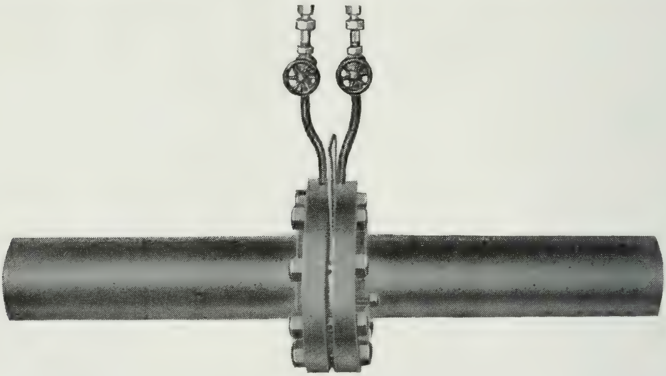


Fig. 66—INSTALLATION SHOWING PRESSURES TAKEN AT THE FLANGES

CORRECTING COEFFICIENTS

This is very important and should be fully understood by meter readers or caretakers as well as the office men reading the charts. Seldom will casinghead gas carry the same specific gravity.

The correction for pressure base need only be made when the orifice meter is first installed. This should be done in accordance with the gas purchasing or selling contract.

Multiplier for Pressure Base Changes

$$\text{Multiplying factor} = \frac{P_b}{P_{bn}} = \frac{14.4 + \text{Pressure Base used in table}}{14.4 + \text{New Pressure Base}}$$

Example: Table based on 0 lb. Pressure Base.

New Pressure Base 8 oz. or 0.5 lb.

$$\text{Multiplier} = \frac{14.4 + 0}{14.4 + .5} = .9664$$

Table 76

MULTIPLIERS FOR CONVERTING COEFFICIENTS FROM 0-LB. PRESSURE BASE TO VARIOUS PRESSURE BASES

Proposed Pressure Base	Multiplier	Proposed Pressure Base	Multiplier
0 oz.	1.0000	1 lb.	.9351
4 oz.	.9829	1½ lb.	.9057
8 oz.	.9664	2 lb.	.8780
10 oz.	.9584	3 lb.	.8276

Multiplier for Atmospheric Pressure Changes

Cases have existed where the average atmospheric pressure varies so greatly from 14.4 as to warrant a change due to these conditions, therefore,

Multiplying factor

$$= \frac{14.4 + \text{Pressure Base used in table}}{\text{Absolute atmospheric pressure} + \text{New Pressure Base}}$$

Example: Average barometric pressure 24.45 inches mercury (12.0 lb. per square inch), Pressure Base 4 ounces; $P_{bn} = 12.0 + 0.25 = 12.25$. lb. per square inch.

Pressure Base in Table 77 is above an atmospheric pressure of 14.4 lb. $=14.4+.00=14.40$ lb.

$$\text{Multiplying factor} = \frac{14.40}{12.25} = 1.176$$

Multiplier for Temperature Base Changes

All other terms remaining the same as the multiplying factor

$$= \frac{T_{bn}}{T_b} = \frac{460 + \text{New Base Temperature (deg. fahr.)}}{460 + \text{Base Temperature (deg. fahr.) used in table.}}$$

Multiplier for Flowing Temperature Changes

Multiplying factor

$$= \sqrt{\frac{T}{T_n}} = \sqrt{\frac{460 + \text{Flowing Temperature of table}}{460 + \text{New Flowing Temperature}}}$$

This factor is usually small, only amounting to one per cent increase in Coefficient for each 10 degrees decrease in temperature and vice versa, that it is not generally applied.

Multiplier for Specific Gravity Changes

$$\text{Multiplying factor} = \sqrt{\frac{G}{G_n}}$$

G = Specific Gravity of table and G_n = New Specific Gravity or true specific gravity of gas

See Table 78.

Table 77—HOURLY ORIFICE COEFFICIENTS FOR GAS

Pressures taken 2½ diameters upstream and 8 diameters downstream.
Atmospheric Pressure 14.4 lb. Pressure Base 0 lb.
Flowing and Storage Temperature 60 deg. fahr. Specific Gravity 1.000
Values of C in $Q = C\sqrt{hP}$ or Q = quantity of gas passing the orifice in cubic feet per hour.

Diameter of Orifice	Diameter of Pipe Line			
	4″	6″	8″	10″
½	53.20	52.88	52.72	52.67
⅝	83.55	......	......	......
¾	121.1	119.6	119.1	118.8
⅞	166.2	......	......	......
1	219.2	214.3	212.7	212.0
1⅛	280.4	......	......	......
1¼	350.6	338.3	334.2	332.5
1⅜	430.1	......	......	......
1½	519.9	493.2	484.6	480.6
1⅝	621.8	......	......	......
1¾	738.2	681.0	665.0	657.5
1⅞	870.2	......	......	......
2	1019.4	904.1	876.4	863.8
2⅛	1189.3	......	......	......
2¼	1382.5	1169.1	1121.8	1100.9
2⅜	1610.8	......	......	......
2½	1856.2	1480.4	1401.2	1368.8
2⅝	2146.8	......	......	......
2¾	2481.9	1851.2	1718.5	1670.0
2⅞	2860.2	......	......	......
3	3296.2	2287.2	2078.8	2004.9
3¼	......	2806.9	2485.1	2371.9
3½	......	3428.1	2950.5	2788.3
3¾	......	4166.8	3474.7	3243.3
4	......	5050.4	4070.0	3742.9
4¼	......	6103.8	4752.4	4296.0
4½	......	7358.2	5519.5	4909.0
4¾	......	......	6411.7	5583.7
5	......	......	7407.7	6330.8
5¼	......	......	8575.8	7164.0
5½	......	......	9906.9	8071.2
5¾	......	......	11406.5	9098.9
6	......	......	13131.1	10225.4
6¼	......	......	......	11481.2
6½	......	......	......	12885.9
6¾	......	......	......	14448.0
7	......	......	......	16196.3
7¼	......	......	......	18125.0
7½	......	......	......	20249.0

Table 78—SPECIFIC GRAVITY MULTIPLIERS

Where the Specific Gravity upon which the Coefficients were calculated was 1.00

Specific Gravity	Multiplier	Specific Gravity	Multiplier	Specific Gravity	Multiplier
.56	1.3363	.91	1.0483	1.26	.8909
.57	1.3245	.92	1.0426	1.27	.8874
.58	1.3131	.93	1.0370	1.28	.8839
.59	1.3019	.94	1.0314	1.29	.8805
.60	1.2910	.95	1.0260	1.30	.8771
.61	1.2804	.96	1.0206	1.31	.8737
.62	1.2700	.97	1.0153	1.32	.8704
.63	1.2599	.98	1.0102	1.33	.8671
.64	1.2500	.99	1.0050	1.34	.8639
.65	1.2403	1.00	1.0000	1.35	.8607
.66	1.2309	1.01	.9950	1.36	.8575
.67	1.2217	1.02	.9901	1.37	.8544
.68	1.2127	1.03	.9853	1.38	.8513
.69	1.2039	1.04	.9806	1.39	.8482
.70	1.1952	1.05	.9759	1.40	.8452
.71	1.1868	1.06	.9713	1.41	.8422
.72	1.1785	1.07	.9667	1.42	.8392
.73	1.1704	1.08	.9623	1.43	.8362
.74	1.1625	1.09	.9578	1.44	.8333
.75	1.1547	1.10	.9535	1.45	.8305
.76	1.1471	1.11	.9492	1.46	.8276
.77	1.1396	1.12	.9449	1.47	.8248
.78	1.1323	1.13	.9407	1.48	.8220
.79	1.1251	1.14	.9366	1.49	.8192
.80	1.1180	1.15	.9325	1.50	.8165
.81	1.1111	1.16	.9285	1.51	.8138
.82	1.1043	1.17	.9245	1.52	.8111
.83	1.0976	1.18	.9206	1.53	.8085
.84	1.0911	1.19	.9167	1.54	.8058
.85	1.0847	1.20	.9129	1.55	.8032
.86	1.0783	1.21	.9091	1.56	.8006
.87	1.0721	1.22	.9054	1.57	.7981
.88	1.0660	1.23	.9017	1.58	.7956
.89	1.0600	1.24	.8980	1.59	.7931
.90	1.0541	1.25	.8944	1.60	.7906

When the Specific Gravity is greater or less than 1.00 multiply the Coefficient by the multiplier opposite the new Specific Gravity if the Coefficient was based upon a Specific Gravity of 1.00

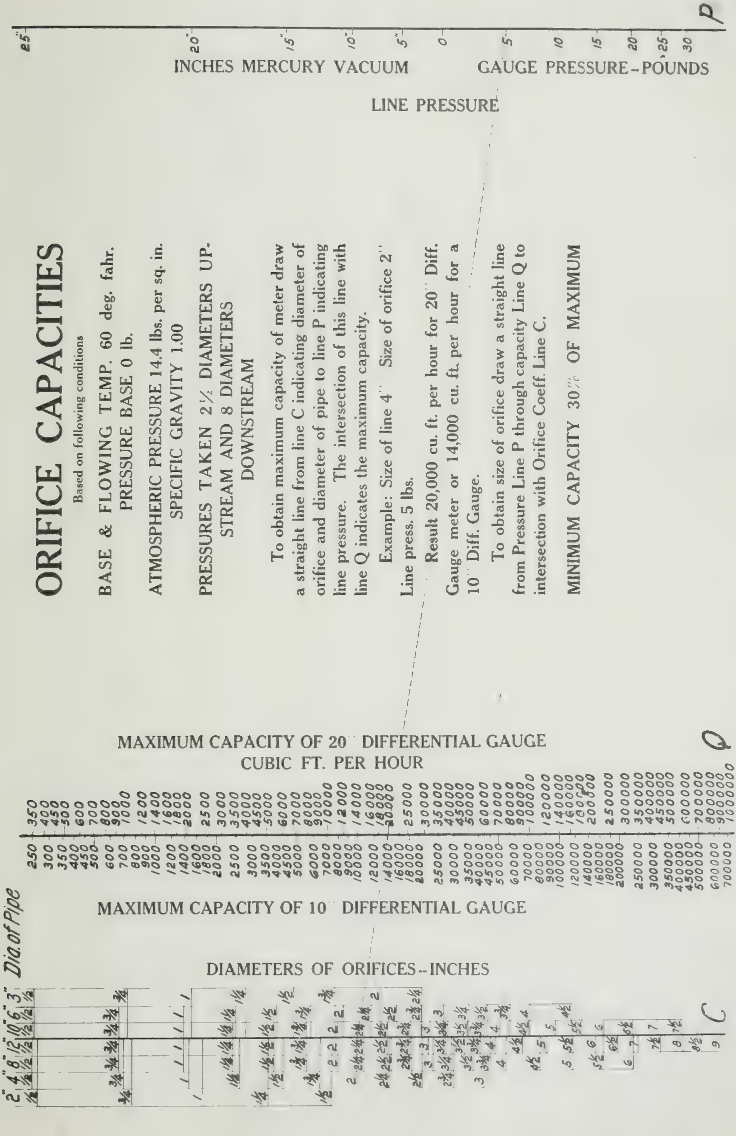

ORIFICE CAPACITIES
Based on following conditions
BASE & FLOWING TEMP. 60 deg. fahr.
PRESSURE BASE 0 lb.
ATMOSPHERIC PRESSURE 14.4 lbs. per sq. in.
SPECIFIC GRAVITY 1.00
PRESSURES TAKEN 2½ DIAMETERS UP-STREAM AND 8 DIAMETERS DOWNSTREAM
To obtain maximum capacity of meter draw a straight line from line C indicating diameter of orifice and diameter of pipe to line P indicating line pressure. The intersection of this line with line Q indicates the maximum capacity.
Example: Size of line 4" Size of orifice 2" Line press. 5 lbs.
Result 20,000 cu. ft. per hour for 20" Diff. Gauge meter or 14,000 cu. ft. per hour for a 10" Diff. Gauge.
To obtain size of orifice draw a straight line from Pressure Line P through capacity Line Q to intersection with Orifice Coeff. Line C.
MINIMUM CAPACITY 30% OF MAXIMUM
INCHES MERCURY VACUUM
GAUGE PRESSURE-POUNDS
LINE PRESSURE
P
MAXIMUM CAPACITY OF 20" DIFFERENTIAL GAUGE
CUBIC FT. PER HOUR
Q
MAXIMUM CAPACITY OF 10" DIFFERENTIAL GAUGE
DIAMETERS OF ORIFICES--INCHES
C
Dia. of Pipe

Fig. 67

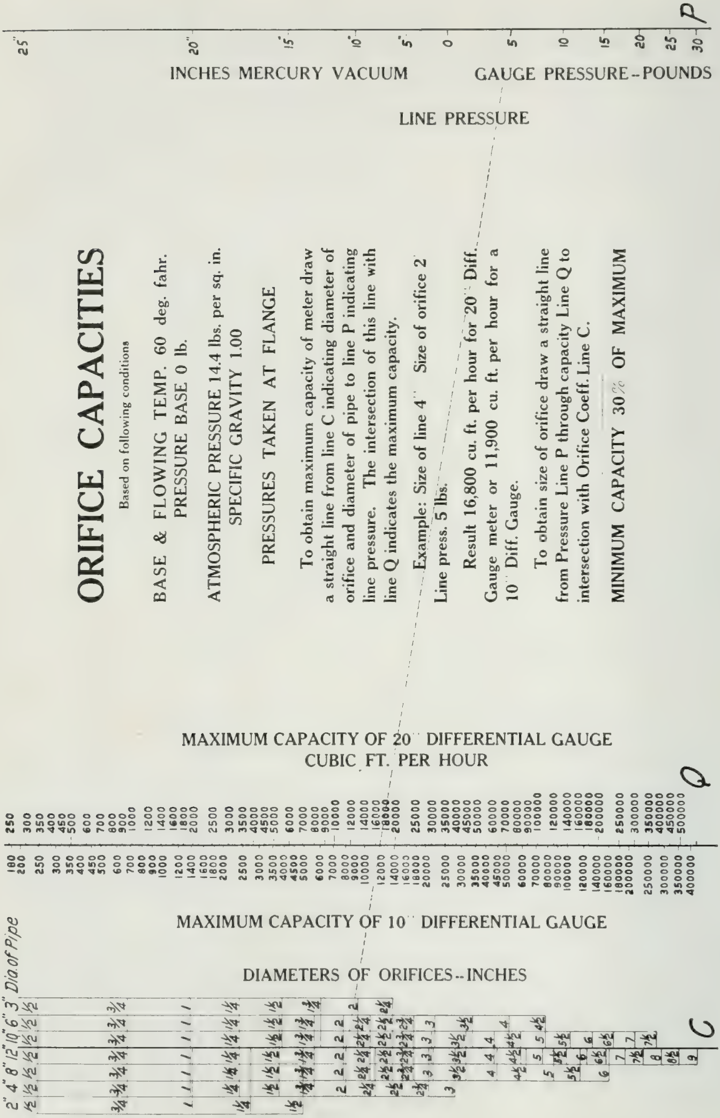

ORIFICE CAPACITIES
Based on following conditions
BASE & FLOWING TEMP. 60 deg. fahr.
PRESSURE BASE 0 lb.
ATMOSPHERIC PRESSURE 14.4 lbs. per sq. in.
SPECIFIC GRAVITY 1.00
PRESSURES TAKEN AT FLANGE
To obtain maximum capacity of meter draw a straight line from line C indicating diameter of orifice and diameter of pipe to line P indicating line pressure. The intersection of this line with line Q indicates the maximum capacity.
Example: Size of line 4" Size of orifice 2" Line press. 5 lbs.
Result 16,800 cu. ft. per hour for 20" Diff. Gauge meter or 11,900 cu. ft. per hour for a 10" Diff. Gauge.
To obtain size of orifice draw a straight line from Pressure Line P through capacity Line Q to intersection with Orifice Coeff. Line C.
MINIMUM CAPACITY 30% OF MAXIMUM
INCHES MERCURY VACUUM
GAUGE PRESSURE--POUNDS
LINE PRESSURE
P
MAXIMUM CAPACITY OF 20" DIFFERENTIAL GAUGE
CUBIC FT. PER HOUR
Q
MAXIMUM CAPACITY OF 10" DIFFERENTIAL GAUGE
DIAMETERS OF ORIFICES--INCHES
2" 4" 8" 12" 10" 6" 3" Dia. of Pipe
C

Fig. 68

PART ELEVEN

Compression Plant.

THEORY OF PRECIPITATION—REFRIGERATION—IMPROVED PROCESS FOR EXTRACTION OF GASOLINE — PLANT CONSTRUCTION AND OPERATION.

THEORY OF PRECIPITATION*

Condensation by Cooling—"The theory of the precipitation of vapors from natural gas is in a way comparable to that of the precipitation of water vapor from the atmosphere. Water vapor is known to exist in the air at all times in varying proportions, but is invisible unless condensed by cooling. Cooling to a temperature below that at which the air is saturated with the water vapor it contains causes precipitation in the form of snow, hail, frost, rain, fog, or dew. This fact is also illustrated by beads of water collecting on the outside of a pitcher of ice water, and by the formation of frost on the refrigeration pipes of expansion units. The air coming in contact with the cold surface of the pitcher or pipes is cooled below its dew point and the moisture which it can no longer hold as vapor condenses as water or frost on the surface. By further cooling of the air more moisture would be condensed, and if cooling were carried far enough practically all of the water vapor could be precipitated without the aid of pressures higher than atmospheric.

Condensation by Compression—In plants compressing air it is found that air, after having been made more dense by increase of the pressure and decrease of the volume, deposits moisture at atmospheric temperature, and as the pressure is increased larger percentages of the contained water vapor are precipitated. Hence either high pressures or low temperatures increase the condensation of the water vapor.

* Bureau of Mines.

In the exceedingly dry atmosphere of the Arizona and Nevada deserts, operating air compressors at a pressure of 100 pounds and cooling the compressed air only to atmospheric temperature always causes precipitation of water, and of lubricating oils from the cylinders, in the air receiver. That all of the moisture in the air is not deposited in the receiver is shown by the fact that in pumps driven by compressed air some moisture freezes in the cylinders and also forms frost on the exhaust outlet.

The condensable fractions in natural gas, like those in air, are not visible under ordinary conditions, but at times the sudden release into the atmosphere of gas from confinement under pressure will cause vapors of hydrocarbons to form a mist resembling fog or steam.

In the treatment of natural gas for gasoline recovery the result desired could be accomplished either by compression or refrigeration, but the complex mixture of gases and vapors complicates the problem. Without an exact knowledge of the various members and the proportion of each to the whole, an attempt to calculate the most suitable pressures and temperatures becomes little better than a guess, and the most practical solution is by tests and experiments. According to the law of partial pressures,* if gas contains 10 per cent of condensable vapor and is under a pressure of 200 pounds, the condensable 10 per cent has acting upon it a partial pressure of 20 pounds, or 10 per cent of the total pressure. As the proportion of different condensable vapors in the gas becomes smaller through their partial condensation, the partial pressure acting on them also becomes less. The percentage of the gauge pressure acting on any one of the gas or vapor constituents varies in proportion to the percentage of volume occupied by that constituent. If the constituent is condensable, condensation will lower its proportion to the

* Lucke, C. E., Engineering thermodynamics, 1912, p. 481.

volume of uncondensed gas to a point at which the partial pressure acting on it is too small to cause further condensation, leaving a portion of the vapor uncondensed throughout the entire treatment. As the acting pressure becomes lower, condensation tends to cease, but lowering the temperature will cause further condensation. Under constant gauge pressures and decreasing temperatures, the larger percentage of the heavier hydrocarbons contained in the gas is recovered, and the losses are confined to the lighter members.

Although all of the condensable vapor and even the true gases can be liquefied by increasing the pressure or reducing the temperature sufficiently, the application of these processes in treating natural gas for gasoline is limited by the commercial considerations. Extremes of either pressure or temperature would yield condensates too volatile for commercial use, also the machinery and other equipment required would be expensive to install and difficult to operate and maintain.

To recover the valuable hydrocarbon fractions that are held as vapors in natural gas, only such pressures and temperatures are necessary as can be obtained by the use of machines and fittings of standard construction and capacities. As the power used to compress the gas heats it, developing power by expanding the compressed gas cools it. By using the cooled gas as a refrigerant, the temperature necessary, in conjunction with the pressures obtained, to extract the maximum of commercial condensate can be developed.

The temperature and the pressure that will yield the most profitable results are those that together will recover the largest possible amount of condensates of low vapor tensions and as much of the lighter parts as can be so blended or handled as to conform with legal standards of safety and make a good motor fuel."

USE OF COMBINATION COMPRESSION AND REFRIGERATION PROCESS

As shown above, the fundamental principles of the compression process are compression and cooling of the natural gas to pressures and temperatures at which certain hydrocarbons condense.

Plants of this character are erected to treat casinghead gas from oil sands or from sands closely associated with oil, the gas being brought to the surface either between the casing and tubing of an oil well or with the oil in the tubing. The quantity of gas from each well is usually comparatively small and in some installations as many as 500 or 600 wells are connected with one compression plant of not more than the average capacity.

The dry (treated) gas is, at most plants, used on the oil leases to drive the gas engines of the compression plant, and also for gas and steam engines in pumping and drilling wells. A few compression plants sell the treated gas for commercial use in cities or for manufacturing purposes. The cost of pipe lines and equipment necessary to deliver the small quantities of gas to market would, in general, be excessive. There is seldom much gas left after the quantity necessary for furnishing power has been used.

The value of the gas for heating, power and lighting is not impaired appreciably by removing the gasoline content. If this gas were not treated, the gasoline would, at most leases, be burned with the gas used for power purposes and practically be wasted as far as serving any useful purpose is concerned."

THE THEORY OF EXTRACTION OF GASOLINE FROM CASINGHEAD GAS, AND ITS APPLICATION IN AN IMPROVED PROCESS*

"The extraction of gasoline from casinghead gas has reached such proportions that, due to installation and operating costs as well as marketing conditions, a cheaper means of recovering this product has been sought. Conditions have been such in the past that quite a nice profit was to be expected from casinghead plants but the casinghead gasoline industry has made no progress along the lines of better methods and research along these lines has been neglected. It has been accepted that subjecting a condensable gas to 250 pounds pressure per square inch and cooling with water while under this pressure, was a standard compression method and that absorbing condensable vapors by some suitable agent and then distilling off and condensing by means of water cooled coils, was a standard method for absorption plants, the compressor plant being used for relatively rich gas and an absorption plant for lean gas. A lack of knowledge as to just what happens to cause the condensation of vapors present in casinghead gas, or at least lack of recognition of the causes, is probably responsible for the lack of further development.

The writer has, for the past two years, conducted experiments which finally reached a point where complete plants were installed following the design dictated by these experiments. Condensate in greater quantities is realized than by other methods, and gas so lean as to be considered suitable only for treatment by the absorption process, has been successfully acted upon and the initial installation costs compare favorably with that of the absorption process. The following is an attempt to explain what takes place when casinghead gas is condensed:

* By Fred E. Hosmer.

Since the recovery of gasoline from gas depends upon extraction of heat in reality, refrigeration is referred to and in order to arrive at a clear understanding, it is necessary first to become familiar with the general thermal properties of the substances encountered.

The molecular theory of matter assumes that all of the chemical elements are made up of small particles, called atoms. When elements combine, such as hydrogen combined with oxygen to form water, the atoms of each element combine to form infinitely small particles, called molecules. Two or more atoms may combine to form molecule. Atoms and molecules, although infinitely small, possess all of the properties of the respective substances. Sufficient heat applied will result in separating molecules into their constituent atoms. They may exist as solids, liquids or as a gas, depending entirely upon the amount of heat that they contain.

The Kinetic Theory states that molecules and atoms are in constant motion. This is greatly restricted in solid bodies by powerful inter-molecular forces, which tend to attract when the molecules are so close together. Motion is less restricted in liquid than it is in solids and practically unrestricted in gases. The application of heat, which is a form of energy, to a substance, increases the Kinetic energy of its molecules, enabling them to increase their motion, overcoming to some extent the strong attractive forces and the addition of sufficient heat to a solid will so increase the energy as to partially overcome the inter-molecular attractive forces and allow increased motion to change the substance from the solid to a liquid state. Further heat, if applied, will further overcome the attractive forces and the substance may become a gas. It is easy to see that this will work backwards by extracting heat from a gas in sufficient quantities that it will become a liquid and by further extraction of heat, it will become a solid.

There is one more physical law which it is necessary to explain, that of partial pressure. A mixture of gases exerts a certain part of the pressure. We say at sea level that the atmospheric pressure is about 15 lb. per square inch. Three pounds of this pressure is due to oxygen in the air and twelve pounds to nitrogen. The percentage of each constituent being in proportion. In other words, the partial pressure of oxygen in these conditions is three pounds and that of nitrogen twelve pounds. When a vapor is mixed with other gases, or other vapors and pressure applied, only a part of the total pressure is exerted on the first named vapor. If this vapor constitutes 10 per cent of the mixture, the pressure on this vapor alone is 10 per cent of the total pressure on such a mixture and if a pure vapor, which will condense at 15 pounds pressure and a given temperature is considered, it being assumed that the vapor under consideration will be the first to condense out, a pressure of 150 pounds will be required to have a pressure of 15 pounds exerted on the first named vapor and to start condensation. In other words, if we take gas and add gasoline vapor to it to the extent that the mixture includes 10 per cent condensable vapor and 90 per cent other gas, and if this vapor should be of such a character that at 15 pounds pressure it would condense, in order to get 15 pounds pressure on this vapor, it would be necessary to exert 150 pounds pressure on the entire mixture. Or, if the percentage be increased so that of the total mixture 20 per cent was this condensable vapor, it would be necessary only to apply 75 pounds pressure to obtain 15 pounds pressure on the 20 per cent vapor. It must be understood that this is assuming that this vapor will be the first to condense and of course, under these pressures and conditions, the condensation merely begins. If we put a certain amount of this mixture in a chamber and apply 150 pounds pressure, assuming that the temperature remains that at which this vapor will condense at 15 pounds, we would expect conden-

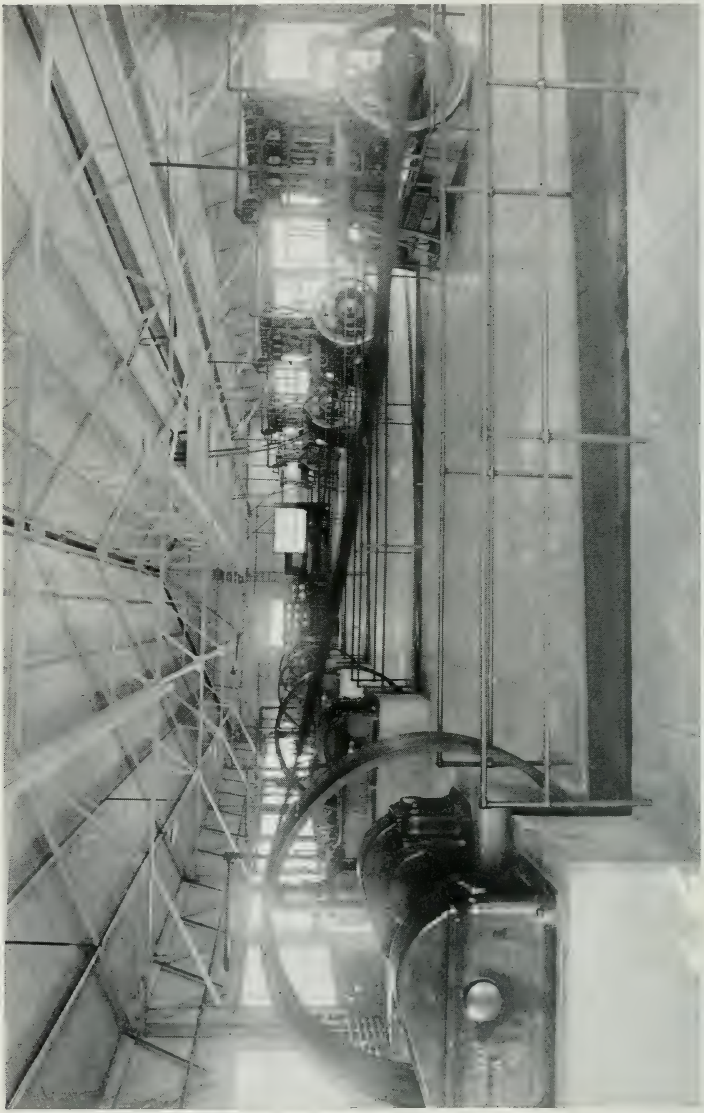


Fig 69—INTERIC 'E UNIT I 'N COMPRESSOR PLANT USING VERTICAL GAS ENGINES

sation to begin—however, in a short length of time there would only be 5 per cent of this vapor so that all other conditions being equal it would be necessary to increase the pressure to 300 pounds and in a very short length of time the pressure would be prohibitive.

It is evident from the foregoing that the application of pressure has by no means all to do with the condensation of gasoline from casinghead gas and it is evident that in some cases gasoline may be condensed from a gas at comparatively low pressures, the pressure depending upon the gasoline contained, and in others it would be necessary to have a higher pressure to even start condensation. But there is no assurance that the low pressure referred to is going to cause all of the gasoline to condense—in fact it is very plain that the opposite would occur so in addition to the action of the law of partial pressures, it is necessary, to recover condensable products, that sufficient heat be removed from the vapor to overcome some of the Kinetic energy contained in it, due to the amount of heat. This is demonstrated every day in the condensation of steam which, of course is a pure water vapor. Water at atmospheric pressure and 32 degrees temperature can be brought to a temperature of 212 degrees by the addition of 180 heat units for each pound of water. However, in order to turn water into steam at atmospheric pressure it is necessary to add, in addition to the 180 heat units which brought the temperature to 212 degrees, 971 heat units, making a total of 1,151 heat units for a pound of water. This additional number of heat units is known as the latent heat of evaporation, it takes over five times as much heat to turn the water into steam without raising its temperature from 212 degrees as it does to raise the temperature of the water alone from 32 degrees to 212 degrees. If steam were available at 212 degrees temperature and atmospheric pressure, condensing it into water at 212 degrees would mean that an amount of heat exactly equal to the latent heat of

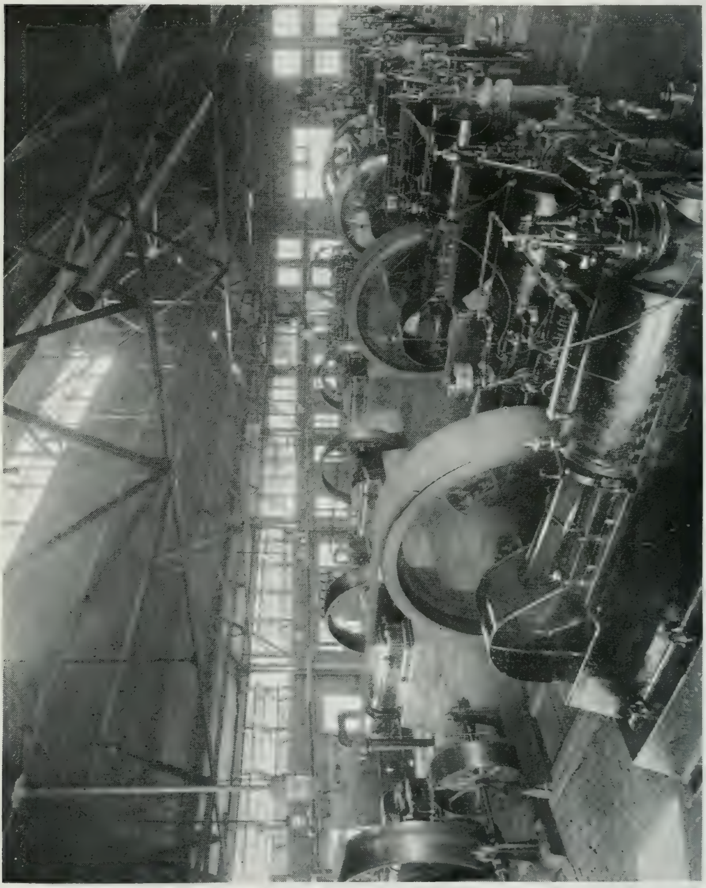


Fig. 70—A COMPRESSION PLANT

evaporation is removed from this steam and in this case may be called the latent heat of condensation and it would be necessary to extract exactly 971 heat units per pound of steam in order to turn it into water at 212 degrees, while only 180 units per pound of water is required to be removed to reduce the temperature to 32 degrees.

The same law applies to condensation of gasoline, regardless of the pressure gone to. The latent heat of condensation must be removed. With the standard method of using 250 pounds pressure and water cooling, this is exactly what happens. It has been shown that comparatively low pressure is required to start the condensation of gasoline in some instances and that after a part of this gasoline is condensed, prohibitively high pressures would be required and this is offset by absorbing the latent heat of condensation which varies with the pressure so that cooling with water and compressing to 250 pounds per square inch in most instances recovers the greater part of the condensable vapor and in some cases further condensation is effected by using an expander. In the latter case the pressure is not increased, but by means of gas of a lower temperature being brought into heat extracting relationship to the gas to be cooled, more of the latent heat of condensation is absorbed, and consequently more gasoline recovered. It is probable, however, further removal of heat will cause further condensation. It is very evident, then, that regardless of what pressure is used, if a medium is employed which can absorb the latent heat of condensation of this condensable vapor the same results will be realized, regardless of pressures. For, when using 250 pounds pressure when the gas becomes the same temperature as the water on the coils, no further heat transfer can be effected, and in the expansion coils if the temperature becomes the same as that of the gas cooling, no further

heat transfer can be effected. The same applies if 125 pounds pressure is used. If after the effect of partial pressure is removed the temperature of the gas at 125 pounds is that of the water cooling same, no further heat transfer and no further condensation can occur without increasing the pressure. However, if further heat by some other means is extracted, the latent heat of condensation must be absorbed if it still remains in the gas. It merely means that a medium with such an absorbing capacity be employed. As it is shown that gasoline will be condensed by the removing of its latent heat of condensation, in turn gasoline will be evaporated by supplying the latent heat of evaporation so that if by any means we cause the evaporation of a given amount of gasoline, it must absorb heat from some source before this can occur and if we should cause evaporation of gasoline in heat extracting relationship to a gasoline vapor, radiation losses being disregarded, the latent heat of condensation of the gasoline would be absorbed by the gasoline being evaporated. This heat in turn would represent the latent heat of evaporation of the gasoline evaporated during a certain portion of it into a vapor. Now if this vapor be withdrawn and more gasoline be placed in the same heat extracting relationship, as further evaporation occurs, further condensation occurs.

While reference is made to partial pressures, this still remains rather vague, as gasoline content may consist of several constituents whose partial pressures vary. The effect, however, is that the gas in the space above the gasoline in the coils, or the gas under compression, due to the evaporated gasoline returning and becoming mixed with gas from the field, is further saturated to such an extent that less pressure is required to condense.

I trust it has been made clear that all matter is composed of infinitely small particles called molecules and that an application of a sufficient amount of heat will result in a separation of these molecules, this heat being a form of energy the Kinetic energy of these molecules is increased. As the Kinetic Theory states that molecules and atoms are in constant motion this increase of Kinetic energy increases the motion. In referring you back to this Theory I am attempting to make it clear that a gas is a gas because it contains sufficient heat to exert sufficient Kinetic energy to overcome the attractive forces which would cause it to become a liquid or, in extreme cases, a solid. Therefore, it is only necessary that we extract from gasoline vapors present in casinghead gas, the natural heat which supplies this Kinetic energy to a point where only sufficient remains to hold it in a liquid state. There is no reason why we should arbitrarily assume that any particular pressure is necessary to condense gasoline from gas. We may take, as a specific instance, the liquid hydrocarbon known as pentane which is a constituent of casinghead gasoline. As a pure vapor, in order to condense pentane, it would be necessary only to hold pressure on it which would equal its vapor tension at any given temperature. For instance, at 86 deg. fahr. pentane has a vapor tension of 11.8 pounds per square inch. At 68 deg. fahr. it has a vapor tension of 8.1 pounds and at 50 deg. fahr. it has a vapor tension of 5.4 pounds and at 32 degrees it has a vapor tension of 3.5 pounds per square inch. In view of this, why would it not be as consistent to say, arbitrarily, that a certain temperature was necessary to recover gasoline. Either statement, made arbitrarily, relative to pressure or temperature, would be erroneous. To say that when we reach a certain temperature all of the gasoline is extracted does not mean anything. We may say, however, that at a certain pressure that a certain temperature would indicate the removal of all gasoline, because the latent heat of condensation would have

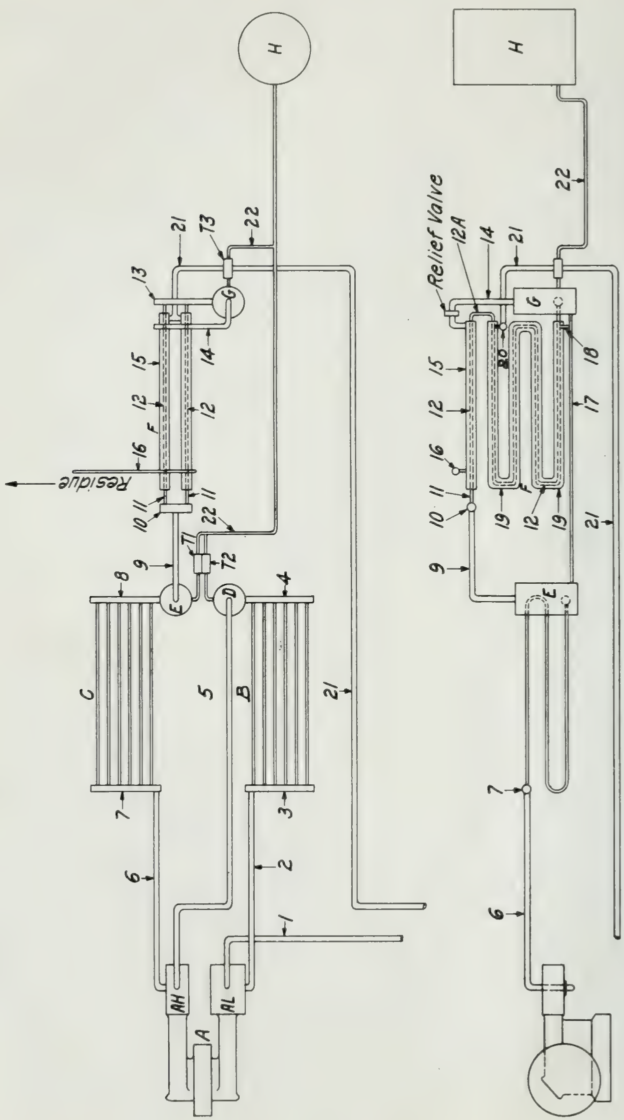


Fig. 71—DIAGRAM OF A COMPRESSION PLANT

to be removed before this temperature could be reached. These pressures and temperatures could not be determined arbitrarily, however the percentage of gasoline present as a vapor would determine this.

The above mentioned principles are applied in the manner as shown in the accompanying sketch, which is entirely diagramatical.

A—is a two-stage compressor.
B—is low pressure coils.
C—is the high pressure coils.
D—is low pressure accumulating tank.
E—is high pressure accumulating tank.
F—is a set of double pipe coils.
G—is the accumulating tank connected to these coils.
H—is stock tank.
T-1.
T-2.
T-3—are automatic traps connected to the accumulating tanks.

The gas when drawn from the field by means of vacuum pump, is delivered by means of Line 1, to the low pressure cylinder of the compressor, indicated by AL. From here, through Line 2 and by means of header 3, gas passes through the low pressure coils and any condensate realized is deposited in the accumulating tank D, which is connected to the low pressure coils B by means of header 4. From the top of the accumulator D, by means of Line 5, the gas passes to the high pressure cylinder indicated by AH. From here, by means of Line 6 and header 7, the gas passes through coils C by means of header 8 into the accumulating tank E, where further condensate is deposited. From the top of this tank E, by means of Line 9 and header 10, the gas passes through a set of double pipe coils indicated by F, which are constructed of 2 in. pipe on the inside of 4 in., the 2 in. entering at the point indicated by 11.

Referring to the elevation view, it will be noticed the top set of double pipe coils is separate from the lower, the gas passing through the top set by means of pipe 12, which is located on the inside of pipe 15 and leaves this top coil by means of pipe 12 A, entering the lower set of double pipe coils, the inside pipe still designated by 12, carries the gas on through this set of coils into the header 13, which is connected to tank G, where any further condensate which is realized in this set of double pipe coils is deposited. The gas then passes by means of Line 14 out of the top of tank G and through the relief valve as indicated in Line 14 and into the large member of the double pipe coils, and surrounds the 2 in. pipe 12 and is allowed to go into the residue line by means of Line 16.

Referring to accumulator tanks E and G, which are respectively high pressure accumulator tank and double pipe coil accumulator tank, pipe 17, leading from these, allows the condensate to enter the outside member 19 of the bottom section of the double pipe coil at the indicated part 18 and, due to the pressure being relieved, this condensate has a tendency to evaporate. This evaporation is drawn up through the outside member 19 of the double pipe coil and out by means of the header 20 and by means of Line 21 is drawn back into the vacuum pump, where it becomes intimately mixed with the gas coming from the field. By introducing gasoline into the outside member of the double pipe coils at a reduced pressure the boiling point of the gasoline is of course lowered. This boiling point is lowered in proportion to the amount of vacuum which is held on the inside of the outer pipe member. The result of having a minus pressure on this gasoline to be evaporated is that the coils are made considerably smaller and it makes it possible to use gasoline for evaporation which at atmospheric pressure would not have as low a boiling point possibly as desired.

The principle of evaporating gasoline in heat extracting relationship to a condensable gas, as mentioned in the foregoing, is applied in exactly the same manner as shown in this sketch. The top section of the double pipe coils, indicated by 15 is used as a pre-cooling coil, the cold dry gas leaving the tank G by means of Line 14 and being expanded to residue pressure of course cools to some extent the gas entering the coils, by means of Line 12. As the evaporation of gasoline cannot take place without its absorbing heat from some source, regardless of the pressure being taken off of it, it is obvious that heat will be absorbed from the surrounding pipe 19, and the material surrounding it, as well as from the pipe 12, which is the inside member or whatever happens to be on the inside of pipe 12. Of course our object is to absorb as much heat as possible from the gas passing through pipe 12 and we eliminate, as far as insulation material will allow, the absorption of heat through the outside member. We have found in some instances that the boiling point of the liquid evaporated reaches as low as 60 degrees below zero. The loss due to radiation through insulating material is overcome to a certain extent by pre-cooling with cold dry gas expanded to field pressure and we hope that the cooling realized by this cold dry gas is sufficient to offset the loss due to radiation in the evaporation coils proper, so that we base the amount of gasoline which is necessary to evaporate, on the amount of gasoline which is recovered in the double pipe coils.

If a million feet of gas is to be handled which carried one-half gallon to the thousand, and no water cooled coils were used, in order to recover this one-half gallon to the thousand, for a plant of a million foot size, expecting the radiation losses of the evaporation coils to be overcome by pre-cooling of the cold dry gas, the amount of gasoline evaporated would equal exactly half a gallon for each thousand feet passed through, plus the amount necessary to actually

cool the gas. This amount is very small, however, due to the low specific heat of the gas.

The principle of partial pressures and the advantages to be derived from increasing the partial pressure on the condensable part of gas, are realized by the intimate mixture of the evaporated gasoline drawn from the evaporation coils with the gas coming from the field. This has the effect of increasing the amount of gasoline realized from the low pressure coils leaving less work for the high pressure cylinder of the compressor to do and, at the same time, has the effect of realizing a greater amount of condensate even in the high pressure coils. Results so far indicate that the greater part of gasoline evaporated in the double pipe coils is recovered in the water cooled coils, in addition to that part recovered in the water cooled coils without the evaporation coils in operation. If this were not the case the process would not be practical for the reason that if one gallon were recovered in the evaporation coils, due to evaporation of one gallon and this one gallon evaporated would not be condensed out until it reached the evaporated coils, it would be necessary to evaporate 2 gallons inasmuch as there would be two gallons to recover. This would continually pile up and in a very short length of time the apparatus would be inoperative. By increasing the percentage of condensable vapor in the gas, however, a greater percentage of the total pressure is exerted on the condensable part and, as explained before, due to this pressure, more gasoline is condensed. The possibility of low temperatures causing freezing up of these coils was at first considered serious but all inconvenience due to this has been eliminated.

One hundred and twenty-five pounds is the maximum pressure required under any circumstance. It may be said that 125 pounds is an arbitrary figure and merely stated as a maximum to be on the safe side. It depends entirely upon the amount of gasoline evaporated, what pressure it is

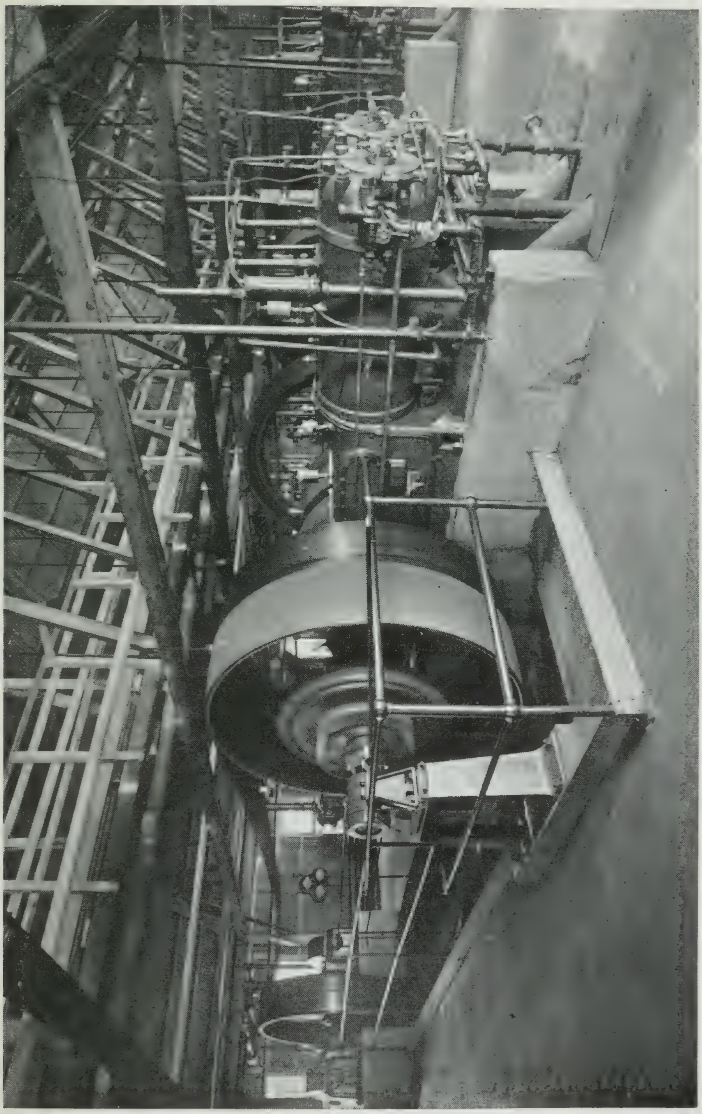


Fig. 72—INTERIOR VIEW OF BELT DRIVEN COMPRESSOR PLANT USING TWIN ENGINES

necessary to go to. In some instances we find 70 pounds is enough.

There has been some question raised as to the horsepower required to handle the additional amount of gas due to the evaporation of gasoline in the evaporation coils. As stated before, slightly more than a gallon of gasoline is evaporated in these coils for every gallon condensed and in the case of a lean gas, for a million feet, there would only be, approximately 500 gallons evaporated. This would amount to only 16,000 cubic feet of gas for the entire million feet handled.

As to the actual horsepower requirements, based on a pressure of 125 pounds, which is used in this case as a maximum in order to show the least possible difference we could expect to realize between the power necessary to operate this process and that to operate under the high pressure method, the following figures are presented:

Fifty hp. is required to compress 375,000 cu. ft. of gas per day of 24 hours from atmospheric to 125 pounds pressure; 210,000 cu. ft. may be compressed to 250 pounds pressure with the same amount of horsepower. This latter figure is based on the practice of installing a 165 hp. engine to handle a 660,000 cu. ft. machine. However, I am giving this installation the benefit of an extra 10,000, assuming that it might handle 700,000 cu. ft. with this same 165 hp. unit.

During a recent test at one plant, a meter proving apparatus was installed which could be used at any time for the same purpose as the meter and at different times the amount of gasoline being evaporated was checked, and as a gallon of gasoline will evaporate into 32 cu. ft. of gas, it was found that when the plant was handling 250,000 cu. ft. a day that 22,000 cu. ft. of gas was the excess handled. On this basis this would mean that we could handle exactly with 50 hp. 345,000 cu. ft. of gas per day from the field. This was taken under average conditions, that of 80 deg. fahr. cooling in the

water cooled coils, handling a very rich gas, and is 110,000 cu. ft. of gas more per day than can be handled with a 50 hp. unit with 250 pounds pressure.

On the basis of one million cu. ft. for a vacuum station and gasoline plant under the same roof, the horsepower requirements would be as follows:

(Vacuum taken at 19 in. which is the pressure generally used in designing a vacuum plant.)

1,000,000	cu. ft. from 18 in. vacuum to atmospheric pressure..	77 hp.	
88,000	cu. ft. from 18 in. vacuum to atmospheric which would be the excess due to evaporation..........	6.8 hp.	
	Total hp. required for vacuum purposes	83.8	
1,000,000	cu. ft. from atmosphere to 125 pounds.............	127.4 hp.	
88,000	cu. ft. from atmosphere to 125 pounds.............	15.4	
		142.8	
	Total required to handle 18 in. vacuum to 125 lb. pressure and extract the gasoline.........................		226.8 hp.
1,000,000	cu. ft. from 18 in. to atmosphere	77 hp.	
1,000,000	cu. ft. from atmosphere to 250 lb. pressure..........	239	
	Total required from 18 in. to 250 lb. pressure and extract the gasoline.....................		316.0 hp.

The amount of excess gas necessary to handle is determined by the amount of gasoline left in the gas upon entering the evaporation coils and no consideration is given here of the advantage derived by additional gasoline being taken out in the low pressure side of a compressor, causing the high pressure side to do less work. It is entirely probable that the greater part of the excess vapor is condensed in the low pressure coils.

It was found at one of the vacuum stations, if operating at 125 pounds without the evaporation coils, we made 80 gravity gasoline in the water cooled coils, that in a few minutes after starting the evaporation coils into operation, the gravity of the gasoline made in the water cooled coils was 90—indicating that considerably more gasoline is recovered in both the low and high pressure cylinders at 125 pounds pressure in the water cooled coils with the evaporation coils in operation, than is recovered without them. This is due entirely to an increase in the gasoline content causing an increase in partial pressures, therefore recovering more gasoline.

It must be understood that the evaporation coils can be installed in connection with high pressure as well as low, and would realize a cheaper installation than that of adding an expander and would have a heat extracting capacity beyond that of an expander.

The advantages derived from the process herein described are, that the installation cost is reduced in the exact proposition that the horsepower requirements are; that less water cooled coils are required; high pressure fittings and tanks are entirely eliminated; the operation cost is reduced, and the necessity of an expander in any case is eliminated.

The two main principles, as applied, are the same as the description of the Patent Claims in the process."

Fig. 73—INTERIOR VIEW OF A SMALL GASOLINE PLANT, SUCH AS ARE COMMON IN THE SISTERSVILLE DISTRICT

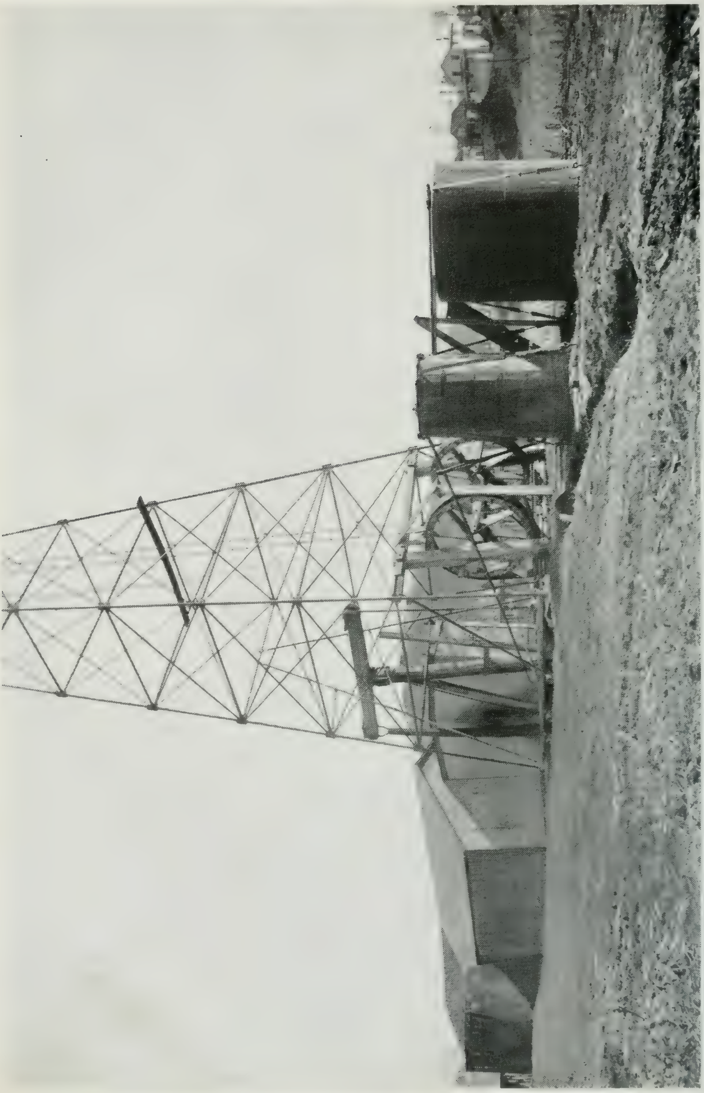


Fig. 74—SMALL GASOLINE PLANT AT THE WELL, IN WHICH ONE GAS ENGINE FURNISHES POWER NOT ONLY FOR THE VACUUM PUMP AND THE COMPRESSOR, BUT ALSO FOR THE PUMPING OF OIL

COMPRESSION PLANT

Casinghead gasoline plants vary in size from single well plants compressing from ten thousand cubic feet of casinghead gas per day and making as small as fifty gallons of gasoline per day to plants with ten and twelve compressors compressing several million cubic feet of gas daily making from thirty to forty thousand gallons of gasoline.

In the former, a fifteen hp. gas engine is used which in addition to furnishing power to run a vacuum pump and a single stage compressor, also furnishes power to the walking beam for pumping oil.

The compressor generally used is a 6 by 6 size running about 250 rev. per min., while the vacuum pump is a Duplex type with much larger cylinders and running about 120 rev. per min. The gas is compressed to about 80 lb. pressure while the vacuum maintained on the oil sand is about 25 to 28 inches vacuum.

At several plants in the Sistersville, W. Va., district the gas is very rich, showing on test as high as 13 gallons of gasoline per thousand cubic feet of gas, consequently, after the extraction of gasoline there is too small a quantity of residue gas left to run the gas engine, compelling the purchase of natural gas from the local gas company.

The gasoline extracted is of 86 deg. to 90 deg. Baume. It is collected in iron drums and hauled by wagon to a nearby market.

Generally one man has charge of three or four plants which are run twenty-four hours daily same as with large installations.

Some of the larger plants in Oklahoma are as complete in every detail and cost as much to install as many of the large gas compressing stations operated by the large natural gas companies.

Fig. 75—COOLING COILS AT A SMALL GASOLINE PLANT SHOWN IN FIGS. 73 AND 74

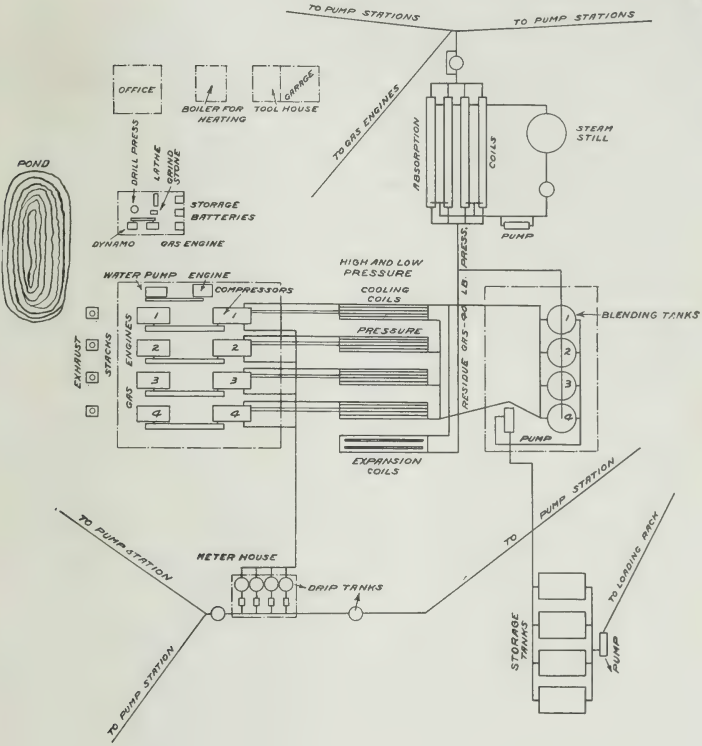


Fig. 76—GENERAL PLAN OF GASOLINE PLANT, COMPRESSOR SYSTEM

In addition to compressors, cooling coils, tanks and gas engines their equipment includes a complete electric lighting system with storage batteries, lathes, drill presses, grinders, overhead crane, a complete water system under fire pressure, a chemical cart for extinguishing fires, private telephone and telegraph lines to main office and to booster stations, a well equipped steam heating system for entire plant, a suitable office, garage and houses for employees.

The completeness and attractive appearance of many plants visited by the author are a credit to their owners. In one instance the meter installation was more complete in every detail and kept in better condition than any similar installation the author has ever seen on a natural gas line.

In the Sistersville district the casinghead gas is compressed to from 80 lb. to 100 lb. and the discharge lines from the compressor lead through tanks containing running water. The coldest water is at the outlet of the coil from the tank.

In the Oklahoma field the casinghead gas is compressed as high as 225 to 275 lb. and the compressed gas is conducted through a series of coils which are cooled by constantly dripping water.

As the compressed gas passes through the cooling coils under high pressure, the hydrocarbons or gasoline condense and are trapped at the discharge end of the coils from which point they are pumped into blending tanks where the desired gravity is attained by blending with naphtha. After blending it is ready for the market.

It may be more profitable to make the lower gravity gasoline (even though less of it is obtained from 1,000 cubic feet of gas) than it is to install expensive machinery and extract a greater number of gallons of high gravity gasoline, because the latter is so volatile that one is able to market but a fraction of the quantity actually made.

Description of Compression Method—If the range of pressures through which the gas is to be compressed exceeds seven or eight compressions, it is necessary to use a two-stage compressor in order to keep the temperature within proper working limits. For this class of work a single two-stage unit is satisfactory.

After the gas is compressed in the low pressure unit or cylinder it passes to the low pressure cooling coils on which cold water is constantly flowing. The gas passes into the

Table 79—DATA SHOWING SITUATION, CAPACITY, AND OUTPUT OF VARIOUS PLANTS, AND THE GRAVITY OF THE PRODUCT*

Field Where Plant is situated	Plant No.	Capacity (in 1,000 cubic feet)	Daily production, gallons	Gallons produced per 1,000 cubic feet of gas	Gravity, deg. Baume
California fields:					
Fullerton	1	1,000	600	0.60	68
Do	2	350	1,200	3.40	76
Do	3	450	700	1.50	78–80
Do	4	1,250	1,600	1.30	72–74
Do	5	5,000	1,200	.24	....
Santa Maria	6	2,500	5,500	2.20	81
Do	7	7,500	7,500	1.00	70
Do	8	500	500–600	1.00	70
Do	9	1,000	2,500	2.50	80
Do	10	750	1,200	1.60	74
Do	11	1,500	3,000	2.00	79
Do	12	700	1,500	2.10	81
Do	13	(*a*)			
Ventura	14	1,000	2,000	2.00	86
Do	15	....	800	....	....
Salt Lake	16	250	325	1.30	65
Do	17	750	840	1.10	60–65
Do	18	....	1,500	....	68–70
Midway	*b* 19	1,800	1,400	.78	68
Do	20	1,500	1,400	.90	67
Do	*b* 21	1,000	700	.70	80
Eastern Fields:					
Bradford, Pa.	22	600	1,200	2.00	96
Sistersville, W. Va.	23	200	800	4.00	88
Do	24	375	1,500	4.00	90
Do	*c* 25	....	....	....	....
Do	26	500	....	....	88
Southern Illinois	27	750	500	.75	83
Do	28	....	200	....	83
Do	29	....	....	....	....

*From Bulletin 151, "Recovery of Gasoline from Natural Gas by Compression and Refrigeration," published by Bureau of Mines.

a Plant not in commission.

b Plant capacities doubled and expansion sets installed or improved; product per 1,000 feet of gas increased.

c At this plant gas is compressed in one stage to a pressure of 150 pounds.

Table 80—DATA SHOWING SITUATION, CAPACITY, OUTPUT OF THE VARIOUS PLANTS, AND THE GRAVITY OF THE PRODUCT*

Field Where Plant is situated	Plant No.	Capacity (in 1,000 cubic feet).	Daily production gallons	Gallons produced per 1,000 cubic feet of gas	Gravity, deg. Baume
Mid-Continent fields:					
Glenn pool......	30	750	3,000	*d*4.00	....
Do...........	31	375	1,500	*d*4.00	77
Do...........	32	3,000	22,500	7.40	84
Do...........	33	1,800	9,000	5.00	82
Do...........	34	750	5,250	7.00	82
Do...........	35	350	1,590	4.52	96
Do...........	36	2,000	2,310	1.10	78
Do...........	37	400	2,565	6.40	85
Do...........	38	750	5,055	6.70	....
Do...........	39	200	510	2.50	....
Do...........	40	250	600	2.40	....
Do...........	41	350	550	1.60	....
South Glenn pool	42	450	1,200	2.40	....
Morris..........	43	300	300	1.00	....
Do...........	44	500	1,850	3.60	....
Beggs	45	350	710	2.10	....
Muskogee.......	46	300	730	2.44	....
Do...........	47	350	300	.85	....
Glen pool.......	48	1,200	2,380	2.00	....
Cushing pool ...	49	2,000	2,810	1.40	....
Cleveland	50	1,200	2,000	1.67	....
Muskogee.......	51	250	925	3.70	....
Do............	52	250	500	*e*2.00	....
Cushing.........	53	....	....	....	....
Nowata.........	54	*f* 2,250	10,000	4.00	....
Do...........	55	1,250	1,600	1.30	....
Do...........	56	380	600	1.60	....
Do...........	57	830	1,500	1.60	....
Morris..........	58	2,000	3,000	1.50	....
Do...........	59	400	725	1.90	....
Nowata.........	60	1,000	1,900	1.90	....
Do...........	61	500	1,100	2.20	....
Do...........	62	280	420	1.50	....

*From Bulletin 151, "Recovery of Gasoline from Natural Gas by Compression and Refrigeration," published by Bureau of Mines.

d Estimated.

e Eight per cent water with high and low pressure product.

f Thirty per cent water with high and low pressure product.

Table 81—DATA SHOWING SITUATION, CAPACITY, AND OUTPUT OF VARIOUS PLANTS, AND THE GRAVITY OF THE PRODUCT*

Field where plant is situated	Plant No.	Capacity (in 1,000 cubic feet)	Daily production, gallons	Gallons produced per 1,000 cubic feet of gas	Gravity, deg. Baume
Mid-Continent fields—Cont'd.					
Glen pool.......	63	487	1,948	*a*4.00	....
Do...........	64	515	2,062	*a*4.00	....
Do...........	65	90	350	*a*4.00	....
Do...........	66	90	351	*a*4.00	....
Do...........	67	98	384	*a*4.00	....
Do...........	68	136	545	*a*4.00	....
Do...........	69	125	500	*a*4.00	....
Do...........	70	141	566	*a*4.00	....
Do...........	71	712	2,864	*a*4.00	....
Do...........	72	375	1,500	*a*4.00	....
Do...........	73	466	1,864	*a*4.00	....
Do...........	74	124	496	*a*4.00	....
Do...........	75	173	690	*a*4.00	....
Caddo (Louis'a)	76	2,000	3,600	1.80	79
Do...........	77	400	640	1.60	79
De Soto (La.)...	78	45	350	7.00	73
Caddo (La.)	79	250	1,050	4.20	*b*80
New Jersey:					
Refinery.........	80	1,750	5,400	3.09	76–93

*From Bulletin 151, "Recovery of Gasoline from Natural Gas by Compression and Refrigeration," published by Bureau of Mines.

a Volume of gas estimated from product at 4 gallons per 1,000 cubic feet, a conservative estimate for gas from wells in the Glenn pool.

b 50 per cent of this product was from low-pressure cylinder and 50 per cent from high-pressure cylinder and expansion coil.

top of the coils and discharges through the bottom of the coils into the accumulator, which collects any gasoline carried along as spray, together with any free gasoline condensed in the coils.

From the low pressure accumulator the gas passes out the top and returns to the high pressure unit or cylinder, where it is compressed to higher pressure (in Oklahoma it is from 225 to 275 lb. per sq. in.)

After compressing in the high pressure unit or cylinder, it passes to the high pressure cooling coil which, like the low pressure coils, is cooled by constantly flowing cold water. From these coils it passes to the high pressure accumulator where the gasoline is separated and the gas passes to the expander compressor or out through a reducing valve to the residue gas line to be used for power or other purposes.

CONSTRUCTION OF PLANT

Plant Sites—In selecting a site for a gasoline plant, consideration must be given to railroad facilities and water supply, in addition to its being centrally located in a casing-head gas field. Many plants are located miles from any railroad and a small sized pipe line is laid to a loading rack on the nearest railroad. This line can be used for pumping either gasoline from the plant to the loading rack or naphtha from the car to the plant.

Single Unit Plan—This plan is copied after the method used by powder manufacturers, and consists of scattering the different operations into many buildings separated over a wide area. It, no doubt, is a safe plan, although somewhat expensive to build and a little more expensive to operate. Yet should a plant suffer an explosion, it would keep down the loss to a fractional part of what it might be where several units are installed in one building.

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Large Single Unit Versus Many Small Units—It is more profitable to use several small compressors than one large one. The latter may be more economical in actual operation, but in case of a breakdown to the compressor, the entire plant is down which means a larger loss.

With an installation of many small compressors, one may be undergoing repairs while the remainder can be kept running, and only a partial loss ensue. Many casinghead gasoline plants are not working 100 per cent capacity, consequently with one unit out of service the load can be thrown on the other compressors with a minimum loss.

Compressors should be shut down occasionally for examination, cleaning and overhauling. This is very easily accomplished with little or no loss where several units are employed.

Another advantage is when the gas supply decreases the number of units can be reduced by moving one to some other location which is impossible where only one large unit is employed.

With the multiple installation the various grades of gas can be treated separately, which is a very important advantage.

It is true that the large single unit is the most economical and develops the largest capacity in proportion to the cost, yet these features are offset when compared with the advantages gained by use of the multiple installation.

Ventilation of Compressor Buildings—The compressor building should be properly ventilated to carry off any gasoline vapors or casinghead gas lying near the floor, to lessen the liability of an explosion. All stuffing boxes on compressors have a tendency to leak slightly and in making repairs some gases will invariably escape into the room when the compressor is first taken apart, especially should the cylinder head have to be removed.

In visiting many plants throughout various oil fields, it is apparent from the design of these buildings, that the ventilation system employed at compressor stations on natural gas lines has been followed, i. e., ventilation in the roof of the building only. This system of ventilation is adequate in natural gas compressor stations as the gas is seldom over .7 gravity, and will consequently rise through the air very readily, but in casinghead gasoline plants the gas is known to run as high as 1.65, and any casinghead gas or gasoline vapor with a gravity greater than 1. would be heavier than air and would naturally flow or drift downward to the floor instead of upward and out through roof ventilators.

In compressor buildings for a casinghead gasoline plant, floor ventilators should be provided so that they can be partially closed in order to properly regulate the draft.

During the warm weather doors and windows in a casinghead gas compressor building are invariably kept open, but during cold weather they are generally kept closed.

The placing of ventilators on the roof only, where the gas is heavier than air reminds one of building a water tank for a gravity system and placing the outlet for the water at the top of the tank.

Fig. number 139, on page 491, illustrates the above suggestion.

Capacity of Compressors—The capacity of compressor cylinders of different diameters, is shown in the following table, based on an actual volumetric efficiency of 80 per cent. This table assumes that the intake pressure of the gas entering the compressor cylinder is at atmosphere and the measurement basis of the gas discharged from the compressor is also at atmosphere (14.4 pounds per square inch absolute.)

Quantity of gas, in cubic feet per 24 hours, compressed by cylinder of one inch stroke, running at one revolution per minute with intake pressure at 14.4 pounds per square inch absolute (equal to atmospheric pressure or 0 pounds gauge.)

Table 83

10	99	21	454	32	1060
11	121	22	499	33	1130
12	144	23	545	34	1197
13	171	24	595	35	1270
14	199	25	646	36	1342
15	231	26	698	37	1418
16	262	27	753	38	1498
17	295	28	810	39	1577
18	333	29	869	40	1660
19	370	30	930		
20	410	31	995		

To ascertain the quantity of gas compressed by a cylinder of any diameter, running at a given number of revolutions per minute, with the intake at atmosphere, multiply the number corresponding to the diameter, taken from the table, by the length of the stroke in inches and the number of revolutions per minute. If the intake pressure is at any value other than atmosphere, multiply the quantity as obtained above by the fraction,

For pressure, $\frac{p+14.4}{14.4}$ For vacuum, $\frac{14.4-p}{14.4}$

Table 84—TABLE OF INDICATED HORSE POWER ON THE COMPRESSOR PISTON PER MILLION CUBIC FEET OF GAS PER DAY

Suction Pressure	Discharge Pressure, Pounds, per Square Inch, Gauge													
	50		60		70		80		90		100		125	
	One Stage	Two Stage	One Stage	Two Stage	One Stage	Two Stage	One Stage	Two Stage	One Stage	Two Stage	One Stage	Two Stage	One Stage	Two Stage
10 In. Vac.	111.3	107.0	123.0	114.0	133.7	121.6	144.3	128.2	......	133.8	......	139.0	......	150.0
5	96.0	95.8	105.7	103.0	115.1	110.5	124.0	116.0	132.8	121.0	141.3	126.2	......	137.8
0 Lb.	84.3	......	93.8	93.8	102.0	100.0	110.0	106.0	117.5	111.2	125.0	116.0	142.7	127.4
5	67.0	......	75.3	......	82.8	......	89.5	......	96.0	95.8	102.2	100.2	116.8	110.2
10	54.5	......	62.5	......	69.5	......	75.9	......	81.8	......	88.8	......	100.0	98.2
15	44.6	......	52.5	......	59.0	......	65.4	......	71.0	......	76.3	......	88.0	......
20	......	......	44.0	......	50.8	......	56.9	......	62.3	......	67.4	......	78.6	......
25	......	......	......	......	43.8	......	49.5	......	54.8	......	59.6	......	71.0	......
30	......	......	......	......	......	......	43.4	......	48.7	......	53.2	......	64.1	......
35	......	......	......	......	......	......	......	......	42.9	......	48.0	......	58.1	......
40	......	......	......	......	......	......	......	......	......	......	42.5	......	53.0	......
45	......	......	......	......	......	......	......	......	......	......	......	......	48.5	......
50	......	......	......	......	......	......	......	......	......	......	......	......	44.0	......
60	......	......	......	......	......	......	......	......	......	......	......	......	......	......
70	......	......	......	......	......	......	......	......	......	......	......	......	......	......
80	......	......	......	......	......	......	......	......	......	......	......	......	......	......
90	......	......	......	......	......	......	......	......	......	......	......	......	......	......
100	......	......	......	......	......	......	......	......	......	......	......	......	......	......
120	......	......	......	......	......	......	......	......	......	......	......	......	......	......
140	......	......	......	......	......	......	......	......	......	......	......	......	......	......
160	......	......	......	......	......	......	......	......	......	......	......	......	......	......
180	......	......	......	......	......	......	......	......	......	......	......	......	......	......
200	......	......	......	......	......	......	......	......	......	......	......	......	......	......

Table 85—TABLE OF INDICATED HORSE POWER ON THE COMPRESSOR PISTON PER MILLION CUBIC FEET OF GAS PER DAY

Suction Pressure	Discharge Pressure, Pounds per Square Inch, Gauge													
	150		175		200		225		250		275		300	
	One Stage	Two Stage	One Stage	Two Stage	One Stage	Two Stage	One Stage	Two Stage	One Stage	Two Stage	One Stage	Two Stage	One Stage	Two Stage
10 In. Vac.	......	159.6	......	168.0	......	176.0	......	182.2	......	189.0	......	194.6	......	200.0
5	......	146.4	......	154.6	......	162.2	......	168.6	......	175.0	......	180.2	......	185.8
0 Lb.	......	136.2	......	144.6	......	151.4	......	158.0	......	164.0	......	169.0	......	174.2
5	130.3	120.0	143.5	127.8	......	134.5	......	141.0	......	146.0	......	151.6	......	156.6
10	112.0	107.6	123.0	114.6	133.8	122.0	144.1	128.0	......	133.6	......	138.6	......	143.4
15	98.5	97.6	108.3	105.6	118.0	111.6	126.9	117.4	135.8	123.0	144.4	128.2	......	132.6
20	88.3	......	97.5	97.0	106.0	103.4	114.2	109.4	122.1	114.0	129.9	119.4	137.4	124.0
25	80.1	......	88.8	......	96.8	96.0	104.2	102.0	111.4	107.2	118.5	112.0	125.2	116.2
30	73.3	......	81.7	......	89.1	......	96.1	95.6	103.0	100.6	109.4	106.0	115.8	110.0
35	67.3	......	75.1	......	82.5	......	89.3	......	95.8	95.4	101.7	100.0	107.7	104.4
40	62.0	......	69.9	......	76.9	......	83.3	......	89.4	......	95.2	94.8	100.7	99.0
45	57.0	......	65.0	......	71.8	......	78.2	......	84.2	......	89.7	......	95.0	94.6
50	52.9	......	60.5	......	67.3	......	73.5	......	79.1	......	84.7	......	89.7	......
60	45.1	......	52.9	......	59.1	......	65.3	......	71.1	......	76.2	......	81.0	......
70	......	......	45.9	......	52.8	......	58.2	......	64.0	......	69.1	......	73.6	......
80	......	......	40.2	......	46.5	......	52.8	......	57.7	......	62.8	......	67.3	......
90	......	......	......	......	41.5	......	47.0	......	52.5	......	57.0	......	62.0	......
100	......	......	......	......	......	......	42.1	......	47.5	......	52.7	......	56.9	......
120	......	......	......	......	......	......	......	......	......	......	43.9	......	48.4	......
140	......	......	......	......	......	......	......	......	......	......	......	......	41.0	......
160	......	......	......	......	......	......	......	......	......	......	......	......	......	......
180	......	......	......	......	......	......	......	......	......	......	......	......	......	......
200	......	......	......	......	......	......	......	......	......	......	......	......	......	......

BY-PASS AROUND A COMPRESSOR

There are two advantages in a by-pass around high and low pressure compressor cylinders. It does away with the necessity of a clutch on the engine, which is a rather expensive accessory and liable to get out of order.

Without a clutch the by-pass can be opened and the compressor would not be working against a pressure when the engine is being started, and practically little power would be required.

The other advantage is that when desiring to shut down, the gas ahead of the compressor can be returned to the field, whereas in the old method it was blown into the air. This practice is considered dangerous, especially should it be a damp, cloudy day.

The by-pass need only be of small sized pipe—two inch would be of sufficient size.

There is little chance of the top gate leaking, as this gas seldom carries any sand which might lodge in the seat of gate and prevent closing it. Should this be considered objectionable one can use two gates with a slip nipple and two sleeves in between the gates. When not in use the nipple and sleeves can be removed and gates plugged.

When the engine is shut down the fly wheel should be blocked with a piece of timber, or the belt unlaced. This will assist in preventing accidents should the engineers desire to work on both the engine and the compressor at the same time.

Oiling Compressors—The forced feed for oil compressor cylinders is the most common in use. One to three drops is forced into the cylinder for each stroke of the piston.

When too much oil is used it has a tendency to give the gasoline a yellowish tinge.

As a rule yellowish colored gasoline is just as good as a clear white gasoline, yet the ultimate purchaser feels it is off grade as well as off color, and that it will not give the power it should. Purchasers exact a penalty for "off color" gasoline.

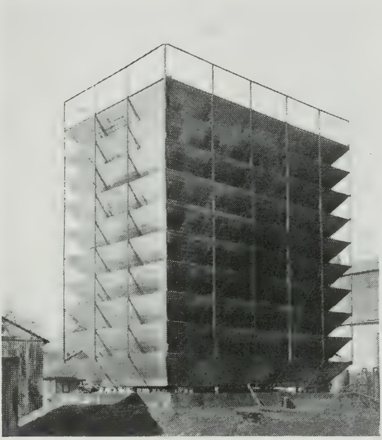


Fig. 77—WATER COOLING TOWER IN WHICH THE WIND FORMS THE COOLING AGENT

Circulating Water—Water must be kept circulating in the jacket of the engine cylinder to cool the walls and make lubrication possible. This requires from four to six gallons per horse power per hour. Where a tank is used its capacity should be such as to allow twenty to forty gallons per horse power.

The water circulating pipes should be free from bends and the top or return pipe should be one half inch larger than the bottom or inlet pipe. The return pipe should enter the tank below the top level of the water therein.

When hard water is used for the jacket put a handful of ordinary washing soda into the tank about once a month.

Circulating water should first be pumped through the compressor cylinder jacket, then through the gas engine cylinder jacket. Tempered water for the latter is far better, while the compressor cylinder will stand colder water.

Residue Gas—Residue gas is the gas coming from a gasoline plant after the gasoline has been extracted. On account of this gas being higher in B. t. u. than natural gas, the latter is hardly the correct name to apply to it.

The volume ratio of dry residue gas to the wet gas before the gasoline is extracted varies, depending upon the quantity and quality of gasoline extracted. Five hundred or more cubic feet of dry gas will remain after extracting the gasoline from 1,000 cubic feet of wet gas.

Some casinghead gas will run greater than 2,500 B. t. u. to the cubic foot, while the average natural gas will run approximately 1,000 B. t. u. The extraction of gasoline by the compression method from one cubic foot of casinghead gas lowers the B. t. u., but on account of the impossibility of condensing and holding all the gasoline in the gas the residue gas may carry as high as 1,500 B. t. u., making it an exceptional gas for all purposes that natural gas is used.

As the absorption process is generally applied to "lean" natural gas under high pressure which may test as low as .64 or lower in gravity and may only produce as low as one tenth or less of a gallon of gasoline to the 1,000 cubic feet of gas there is very little change in the gravity or in the B. t. u. in the gas. In extracting gasoline from "lean" natural gas by the absorption process, the term residue is not applied to the gas after the gasoline has been extracted but it is properly termed natural gas.

Residue Gas and Absorption Method—Some companies state that it is profitable to apply the absorption process to the residue gas before distributing the gas for power. This is done by installing a system of large pipe coils to act as horizontal absorbers.

The number of coils is dependent upon the quality of the gas and the amount to be treated. The gas must pass slowly through the oil to allow all of the gas to come in contact with all of the oil.

The oil is pumped into coils and the gas pressure in the coils gives the oil a flowing pressure to the steam still. The inlet and outlet of oil lines should be so regulated as to keep a constant level in the coils.

Torch oil or mineral seal oil can be used successfully.

A glass gauge can be installed on each joint of 12 in. pipe to assist in maintaining a constant oil level in the coil.

While the results may be judged by the gasoline recovered in the still, an analysis of the gas before and after entering the coils will more accurately determine whether the coils are operated successfully or not.

Solution of Gas in Condensates—One of the physical changes occuring in the operation of a gasoline plant has to do with the solution of gas in the condensate, that is, when the residual gas is in contact with the condensate in the storage tank. The following experiment and calculation will serve to show how small and insignificant this change may be.

A residual gas from an operating plant was shaken with refinery naphtha. The naphtha had a specific gravity of 61 deg. Baume. The solution was effected at a temperature of 20 deg. cent. (68 deg. fahr.) and atmospheric pressure. The naphtha was shaken with the gas supply until no more gas would go into solution. It was found that 1 liter of the naphtha dissolved 1.760 liters of the gas; or 500 gallons of naphtha would have dissolved 3,331.7 liters of the gas. If the assumption be made that this residual gas was ethane only, then it can be calculated that 3,331.7 liters of gaseous ethane at 16 deg. cent. (60 deg. fahr.) and 30 inches of mercury is equivalent to 2.7 gallons of liquid ethane. This

quantity of liquid is so small as to seem insignificant, although in regard to raising the vapor pressure of the condensate it is important.

Interpretation of Results of Tests (from Bulletin No. 88 Bureau of Mines)—"Many experiments have shown that gasoline may be obtained from natural gas having a specific gravity of 0.80 and higher (air = 1). Some inconsistencies have been noted, however, so that the authors would hesitate to recommend the installation of a plant to handle a gas that tests showed to have a specific gravity as low as 0.80 or to have an absorption percentage of 30.0 (Bureau of Mines test), although the gas might be all right for the purpose, especially if it were from wells in a field where other gases of low specific gravity were already producing gasoline. The authors believe, however, that a gas with a tested specific gravity as high as 0.80 and an absorption percentage as high as 40 might warrant an installation.

Natural gases differ in composition. A so-called 'wet' gas might, for instance, contain a very large proportion of methane, with little ethane, propane, or butane, but enough of the gasoline hydrocarbons to warrant a plant installation. Such a gas when subjected to comparatively low pressures would deposit the gasoline vapors. Another gas of the same specific gravity might contain a comparatively small proportion of methane and ethane and a large proportion of propane and butane, but not enough of the gasoline hydrocarbons to warrant plant installations. Therein lies the reason why specific gravity, solubility, or combustion tests cannot always be relied on.

In regard to natural gas of low specific gravity and low absorption percentage (known as a 'lean' gas), the safest recourse is to test by methods described in Part 7, or by means of a portable outfit consisting of a gas meter, small gas engine, compressor, cooling coils, and receiver. Such an outfit can be hauled from place to place

on a wagon. This method is in all cases to be recommended as having distinct advantages over laboratory tests or any other testing method if it is desired to obtain data for erection of a compression plant. However, it is true that tests made with the portable outfit may be misleading unless in charge of a careful and experienced person.

Table 86

RESULTS OF TESTS OF THE GRADE AND QUANTITY OF GASOLINE PRODUCED WHEN CRUDE CASINGHEAD GAS IS SUBJECTED TO DIFFERENT PRESSURES

Pressure	Temperature of cooling water	Gravity of gasoline	Yield of gasoline per 1,000 cubic feet of gas
Pounds per square inch.	*deg. Cent.*	*deg. Baume*	*Gallons*
110	10	..	1.8
140	10	90	3.0
190	10	94	4.5

It has been found by experiment at this plant that pressures of 140 to 150 pounds per square inch produced the most marketable gasoline. It will be observed that a pressure of 190 pounds produced more gasoline. The extra 1½ gallons, however, was of such a volatile character that it only escaped into the atmosphere upon exposure to the air; hence high pressures at this plant were unnecessary. Gasoline could be obtained by the application of pressures as little as 50 pounds per square inch, but the yield was small.

As casinghead gas is of different character in different sections of the country and even in the same oil field, data obtained at one plant can not always be used as a basis for operating other plants—that is, as far as the pressures that

should be used are concerned. Each operator should thoroughly test his own gas. Different pressures should be applied and the quantity and character of the gasoline noted. A reliable meter for measuring the gas becomes indispensable. If, in certain plants operating to-day, meters were installed and a series of tests conducted as above outlined, much greater efficiency of operation could be attained. Other apparatus that could be used to advantage are thermometers, graduated vessels for measuring the gasoline, hydrometers for determining the specific gravity of the gasoline, and gas-analysis apparatus, especially an apparatus for detecting air leaks in pipes through analysis of the gas for oxygen."

ACCUMULATOR AND MAKING TANK BUILDING

It is necessary for the successful operation of a plant that the stock and making houses be built of cement in order to exclude the heat, so far as possible, during the hot season. Gasoline is so very volatile that heat produces a high pressure in the storage tanks.

In building accumulating tanks it is best to build them above ground. As gasoline gas is very heavy it lies near the ground or floor, consequently where pits are used, the opportunity for ventilation is small and the danger of explosion or asphyxiation is increased.

All accumulating tank or storage tank buildings should be built with ventilators near the ground as well as in the roof.

Accumulator Tanks—The lower cock of the gauge glass should be installed above the water drain in an accumulator tank. This will prevent water raising in the glass, freezing and breaking it.

The placing of ¼ in. mesh wire screen around gauge glasses on any tanks will not only protect the glass but should it break when being read, it will prevent the glass from flying and injuring the gauge reader.

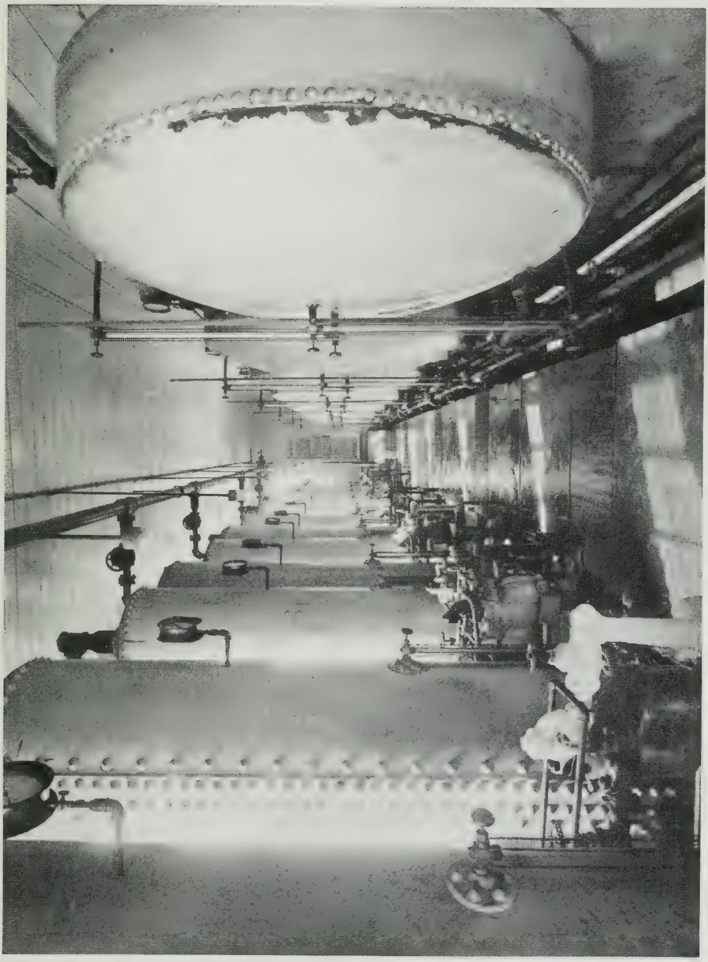


Fig. 78—INTERIOR VIEW OF ACCUMULATOR HOUSE SHOWING ACCUMULATOR TANKS, TRAPS, ETC.

Table 87

EXPANSION OF STEAM PIPES

Expansion for 100 Feet of Length of Pipe for Different Temperatures Fahrenheit, as Given by The Practical Engineer, January, 1911

Increase in Inches per 100 Feet

Temp., deg. fahr.	Approximate Corresponding Pressure of Saturated Steam	Wrought Iron	Steel	Brass and Copper
0		0.00	0.00	0.00
50	29.6 Mercury Vacuum	0.40	0.38	0.57
100	28.0 Mercury Vacuum	0.79	0.76	1.14
150	22.0 Mercury Vacuum	1.21	1.15	1.75
200	5.1 Mercury Vacuum	1.65	1.57	2.38
250	15.2 Lb. Gauge	2.09	1.99	3.02
300	52.3 Lb. Gauge	2.58	2.47	3.74
350	120.0 Lb. Gauge	3.08	2.94	4.45
400	231.0 Lb. Gauge	3.63	3.46	5.24
450	405.0 Lb. Gauge	4.28	4.08	6.18
500		4.90	4.67	7.06
550		5.55	5.30	8.03
600		6.26	5.98	9.06
650		7.05	6.71	10.18
700		7.86	7.50	11.37
750		8.75	8.36	12.66
800		9.76	9.31	14.10

Installing Plant Lines—The return line from the accumulator tank to the high pressure compressor occasionally shows or makes gasoline which is injurious to the high pressure cylinder. To prevent this the line could be heated slightly by laying it along side of the discharge line from the low pressure cylinder. The temperature of the gas returning to the high pressure cylinder should only be raised a few degrees in temperature. In addition to this a pipe drip should be installed on the line at a point near the high pressure cylinder. The return line should have a slight slope or dip toward the accumulator tanks.

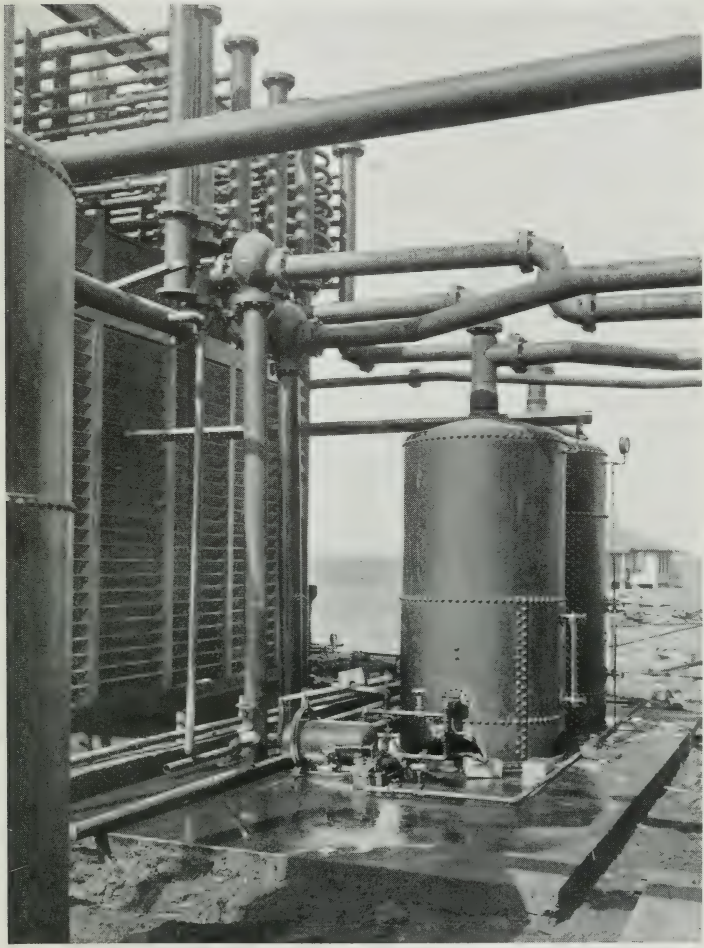


Fig. 79—ACCUMULATOR TANKS BEFORE HOUSING IN
Note welded pipe joints

When gasoline enters the high pressure cylinder with the gas, it has a tendency to cut out the oil from the piston rings and will eventually ruin them.

Some compressor manufacturers use two ½ in. piston rings in one groove. Some operators make it a practice with new compressors, when shut down due to defective or worn out rings, to increase the width of the rings by placing a ring one inch wide in place of the two half inch rings.

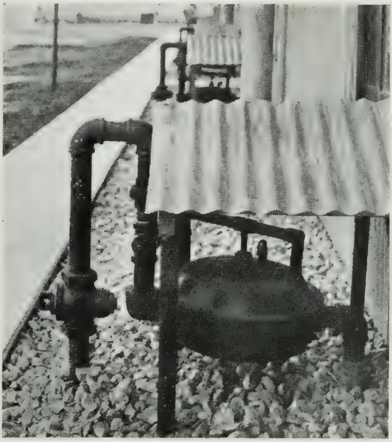


Fig. 80—SENSITIVE REGULATOR ON SUPPLY LINE TO GAS ENGINE

Horse Power of Gas Engines—The horse power of a gas engine is usually rated as the actual power delivered to the belt on average fuel. This power delivered to the belt bears a close relationship to the power developed in the cylinder and the more excellent the design and construction of the engine the more nearly will these two powers be equal.

Power is developed by compressing a mixed charge of gas and air in the cylinder and then igniting it. The heat produced by the combustion causes the gases to expand and

exert a pressure on the piston which drives the latter forward to the end of its stroke when the pressure is released by means of the exhaust valve.

The pressure due to rapid combustion is the same for any size engine provided the compression and mixture are the same and the horse power of the engine depends upon the size of the cylinder.

Various ratings are used to designate the size of an engine, but the surest guide to comparative power is to compare the sizes of cylinders.

Size for size a two cycle engine will develop something less than twice the power of a four cycle engine.

In buying engines, do not be guided altogether by horse power rating, but look well into cylinder sizes to determine whether the engine is large enough to justify its rating.

Stopping Gas Engines in Case of Accident—Primarily it should be said that is case of accident all engines should be shut down as quickly as possible, either by shutting off the gas supply at the engine or outside of the building.

Under no circumstances should an employee attempt to stop an engine by pulling off the electric wiring to the spark plug. The wire, if pulled from the spark plug, might make a spark on it at the instant of disconnecting or where-ever it came in contact with the engine or other machinery. Should the engine room be filled or partially filled with gas due to an accident to the compressor, the spark made by the wire would cause an explosion in the building just the same as it would within the gas cylinder. The wires from the spark plugs could be run to a switch just outside the door nearest to each engine. This would be just as safe to operate as shutting off the gas, and the result quicker.

In addition to this, the stopcock on the inlet to the gasometer could be permanently equipped with a long wrench by the use of which the gas supply to the engine could be quickly cut off.

The flow of gas to the gasometer is generally controlled by one low pressure regulator at a point farther away from the compressor building than the gasometer. This low pressure regulator is worked by a weight on an arm, which, if kicked out (if not being held by a pin) will cut off the gas supply. This would affect all engines at once, whereas shutting the stopcock at a gasometer would only affect one engine.

Table 88

Length and Diameter of Services for Small Gas Engines

Horse Power of Engine	50 Feet of Pipe Diam. In.	100 Feet of Pipe Diam. In.	150 Feet of Pipe Diam. In.	225 Feet of Pipe Diam. In.
5	1	1	1¼	1¼
10	1¼	1½	1½	1½
15	1¼	2	2	2
20	1½	2	2	2
30	1½	2½	2½	2½
40	2	2½	2½	3
50	2½	2½	3	3

Multiply the horse power of the engine by 0.03 and add three quarters of one inch to find the proper size of gas supply pipe.

Lighting Plant—While there is danger of explosion due to the breaking of an incandescent light bulb in an explosive mixture of gas and air, nevertheless the electric light furnishes the least dangerous method of lighting a gasoline-gas plant and should invariably be used. Good ventilation should always be provided to prevent the accumulation of gas, and all light bulbs should be guarded to prevent breakage.

Gas Relief Regulator—This regulator is of special interest to gasoline makers.

Table 89

SHOWING PROPER SIZE DIAPHRAGM TO BE USED IN GAS REGULATORS FOR DIFFERENT PRESSURES

Pressure at Outlet in Pounds	High Pressure Regulators						Low Pressure Regulators to Cut to Ounces		
	1 In. Regulators		2 to 4 In. Regulators		6, 8, 10 and 12 In. Regulators				
	Size Diaphragm	Size Diaphragm Case	Size Diaphragm	Size Diaphragm Case	Size Diaphragm	Size Diaphragm Case	Size Regulator	Size Diaphragm	Size Diaphragm Case
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
5	14	17½	16	19½	23	26½	1	10	13½
10	11	14½	12	15½	16	19½	2	16	19½
20	7	10½	8	11½	12	15½	4	20	23½
30	6	9½	6½	10	9	12½	6	34	37½
50	5	8½	5	8½	7	10½	8	30	33½
75	4	7½	4	7½	5	8½	....	....	....
100	3	6½	3	6½	5	8½	....	....	....
200	2½	6	2½	6	3	6½	....	....	....

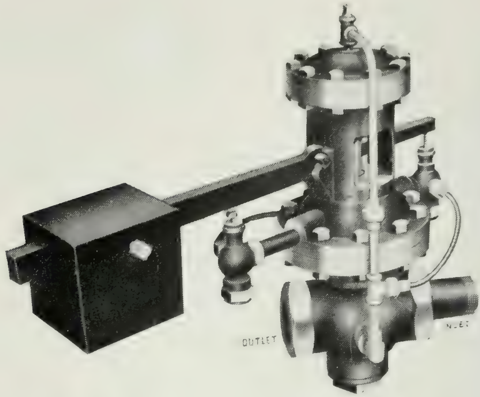


Fig. 81—GAS RELIEF VALVE OR REGULATOR FOR GASOLINE PLANTS

After the gasoline has been compressed to a high pressure, generally about three hundred pounds per square inch, this type of regulator will reduce the pressure to twenty or thirty pounds and retain that pressure. If the pressure ahead of the regulator drops below that at which it is set, it will cut off. In other words it acts the opposite of a standard regulator used in distributing gas.

Exhaust Pipe—The exhaust pipe should be as straight and free from bends as possible and the outlet also should be shielded to prevent rain collecting in it. The diameter of the exhaust pipe should be between one-third and one-quarter of the cylinder diameter.

Expander-Compressor—A casinghead gas expander-compressor consists of a high and low pressure expanding cylinder, direct connected to a duplex single or double stage compressor by which work is done to accomplish reduction in temperatures by expansion of the gas. The dry gas from the top of the double pipe coil accumulating tank is admitted into the high pressure cylinder of the expander

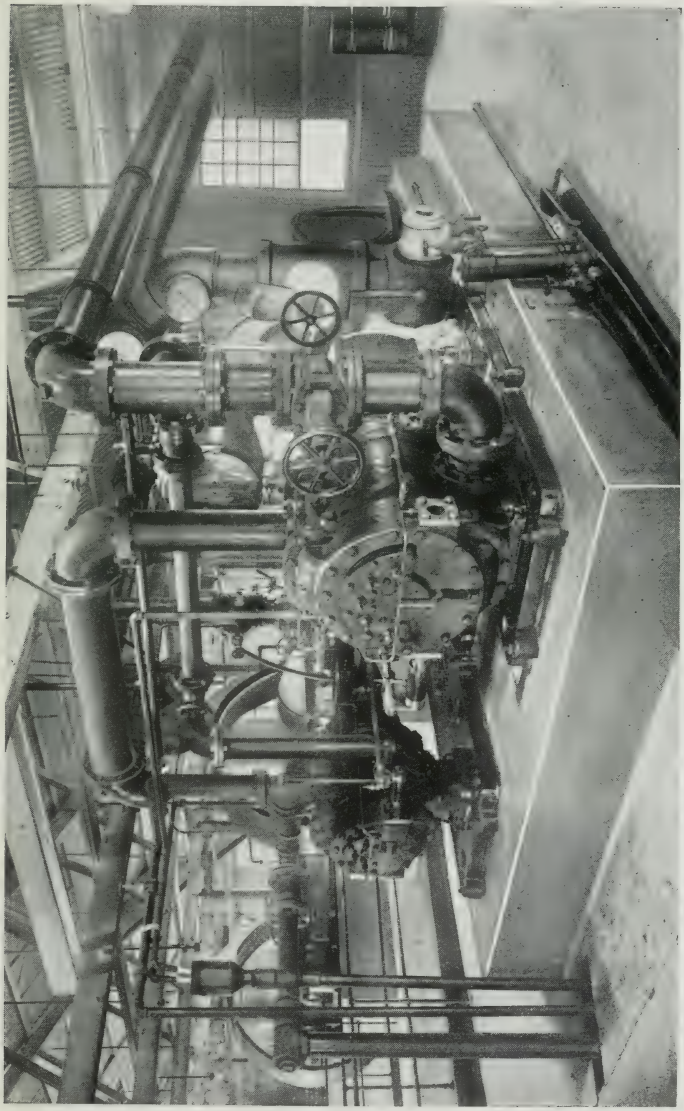


Fig. 82—AN EXPANDER USED TO INCREASE THE YIELD OF GASOLINE EXTRACTED FROM CASINGHEAD GAS.
Expander is Installed on Gas Lines After Gas Leaves the Cooling Coils

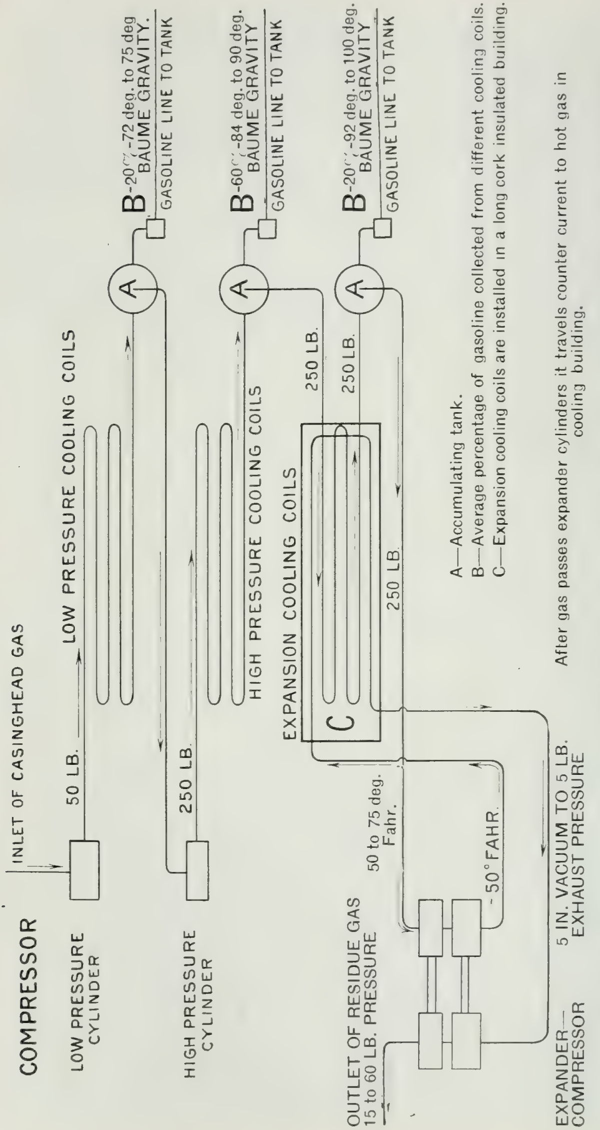


Fig. 83—DIAGRAM OF A COMPRESSOR, COOLING COIL, ACCUMULATING TANKS AND EXPANDER

Showing Pressures and Average Percentage of Gasoline Collected at Each Collecting Plant

at from 250 to 300 pounds pressure and is expanded to about 50 pounds pressure; it then passes into the receiver of the low pressure expanding cylinder and is expanded in the low pressure cylinder to the neighborhood of five pounds pressure, and sometimes to as low as five inches vacuum at the exhaust outlet. The expansion of the gas is regulated by hand cut-off valves on both the high and low pressure cylinders. The expanded gas, due to its low temperature, is used for the further cooling of the casinghead gas after it leaves the high pressure water cooled coils and accumulator tanks. The expanded gas leaves the exhaust of the expander at a temperature of from 40 to 60 degrees below zero fahr. and passes through a set of double pipe coils counter current to the travel of the casinghead gas. These coils are generally inclosed in a long narrow cork insulated house. After the cooling gas has passed through the double pipe coils it passes on to the intake of the duplex single stage or two stage compressor, as the case might be, and is discharged by the compressor into the field return line, where the gas is used for fuel.

The amount of gasoline that can be extracted from casinghead gas by the use of an expander-compressor depends entirely on the efficiency of the water cooled coils. With proper designed water cooled coils and sufficient cooling water the expander-compressor generally adds from six to ten per cent of the gasoline yield. While with poorly designed and inefficient water cooled coils, due to scarcity of cooling water or other causes, the expander-compressor in some cases, has decreased the yield of the gasoline as high as twenty per cent.

Owing to the extreme low temperatures within the cylinder walls of the expansion cylinders it has been found quite difficult to properly lubricate the valves in cylinders; in fact, the only dependable lubricant so far found is glycerine.

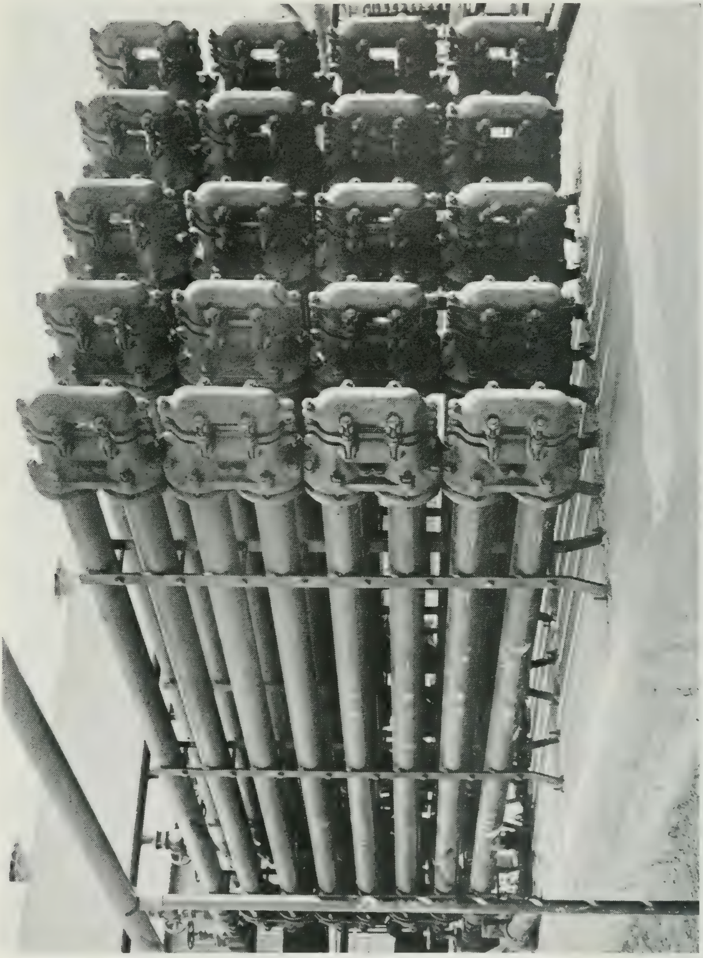


Fig. 84—EXPANDER COILS BEFORE COVERING WITH CORK AND HOUSING

In some cases the compressor end of the expander-compressor is used to compress casinghead gas instead of compressing the dry gas for its return to the field. When the compressor end of the expander is used for compressing casinghead gas it is then necessary to use auxiliary machinery to discharge the dry gas to the field for fuel.

See diagram, Fig. 83 on page 332 and illustration, Fig. 82 on page 331.

Description of Ordinary Ammonia Refrigerating Machine (From Bulletin 88, Bureau of Mines)—"An ordinary ammonia refrigerating machine, such as is used for cooling purposes, consists in general, of three parts—a refrigerator or evaporator, a compression pump and a condenser.

The refrigerator, which consists of a coil or a series of coils, is connected to the suction side of the pump, and the delivery from the pump is connected to the condenser, which is generally of somewhat similar construction to the refrigerator. The condenser and the refrigerator are joined by a pipe in which is a valve, called the regulator. Outside the refrigerating coils is the air, brine, or other substance that is to be cooled in the refrigeration system and outside the condenser is the cooling medium, which is water. The liquid ammonia passes from the bottom of the condenser through the regulating valve into the refrigerator in a continuous stream. As the pressure in the refrigerator is reduced by the pump and maintained at such a degree as to give the desired boiling point—which is, of course, always lower than the temperature outside the coils—heat passes from the substance outside through the coil surfaces and is taken up by the entering liquid, which is converted into vapor. The vapors thus generated are drawn into the pump, compressed, and discharged into the condenser, the temperature of which is somewhat above that of the cooling water. Heat is

transferred from the compressed vapor to the cooling water, and the vapor is converted into a liquid which collects at the bottom and returns by the regulating valve into the refrigerator. The compressor may be driven by a gas engine or in any other convenient manner. The pressure in the condenser varies according to the temperature of the cooling water, and that in the refrigerator is dependent upon the temperature to which the outside substance is cooled.

Anhydrous ammonia is a gas at ordinary temperatures and under atmospheric pressure. The liquid anhydrous ammonia is commercially sold in iron drums in which it is contained under a pressure varying between 120 and 200 pounds per square inch, the pressure in the drum depending on the temperature of the liquid in it.

Some idea of the nature of the natural gas condensate obtained can be had by considering the liquefaction points of the constituents that are found in natural gases used for gasoline condensation. The boiling point of liquid propane is—45 deg. cent. (—49 deg. fahr.), and of liquid butane 1 deg. cent. (34 deg. fahr.)

The lowest temperature obtained in the refrigerating coils of the Olinda plant is — 10 deg. cent. (14 deg. fahr.) Hence it can be accepted that no propane is liquefied, but some butane and higher paraffins are. The efficiency of the extraction of the condensable constituents from the natural gas for any given temperature will depend upon the velocity of the gas through the coils, or, what is the same thing, the area of cooling surface. Heat is, of course, extracted from the natural gas when it enters the cooling system. If the cooling area of the pipes is not great enough, the residual natural gas will leave the system still containing gasoline vapors that could have been condensed by further cooling treatment. By proper experimentation the amount of cooling surface required to produce the greatest quantity of salable condensate can be ascertained. Presumably the

Fig. 85—AMMONIA REFRIGERATION PLANT WORKING ON THE RESIDUE GAS FROM A COMPRESSION PLANT

operators of the Olinda plant have made such a determination. They believe that the refrigeration method offers much promise and that more plants of this type will be installed.

In the United States at least 85 per cent of the refrigeration plants used for various purposes use ammonia as the refrigerant. Other refrigerants that may be used are sulphur dioxide, carbon dioxide, and water vapor."

APPLICATION OF AMMONIA REFRIGERATION TO CASINGHEAD AND "LEAN" NATURAL GAS

Considerable work has been done during the past few years in the application of mechanical refrigeration to the recovery of casinghead gasoline; and some in the treatment of dry natural gas. Some difficulty in the operation of especially low temperature systems on gasoline condensation has been found in the gradual obstruction of the apparatus by the freezing of moisture from the gas. The first requirement was that a system to be practical should be capable of being operated continuously.

When gas containing condensable gasoline vapor is compressed and cooled the vapor gathers in minute particles suspended in the gas; this "foggy" condition can be noticed in gauge glasses where the liquid is sufficiently low to allow a circulation of gas through the glass. These particles are too small in quantity and size to precipitate readily and when the gas is in motion a considerable amount of gasoline will remain suspended in the gas and be lost.

A further loss occurs by reason that the point at which the lowest temperature is reached by the gas (the outlet of the coils) is not the point of separation, but the final separation is in the accumulator tank, which is sometimes a considerable distance from the coils. Particularly in warm weather the gas rises in temperature before reaching the accumulator

tank and some of the gasoline is re-evaporated. In one case noted the temperature of the gas leaving the accumulator tank was fourteen degrees higher than at the outlet of the coil.

These considerations lead to the development of the "direct contact" or scrubber system of cooling.

In this system when applied to residue gas, the gas is taken from the outlet of the high pressure accumulator and brought into the bottom of a vertical shell fitted with suitable baffling arrangements. Over these baffles is showered a refrigerated fluid such as salt or calcium brine which, in passing down over the baffles, comes in direct contact with the gas passing in an upward direction through the baffles. This affords a most efficient cooling contact between the gas and liquid allowing the apparatus to be very compact.

The passing of the gas through successive sprays of falling cold liquid carries down by the scrubbing action the particles of gasoline suspended in the gas in a finally divided state.

The mixture then passes through a separator where the gasoline rises to the top and flows off to the trap, the brine returning from the bottom of the separator to a circulating pump which forces it through the brine cooler and again to the top of the scrubber. The moisture in the gas is absorbed by the brine resulting in a gradual dilution of the brine. A portion of this brine solution is drawn off intermittently to a tank where it is concentrated by the application of heat in a convenient manner such as the steam coil, the concentrated solution being then returned to the circulating system. The withdrawal of about one-third of the brine in the system about once a week will dispose of the moisture absorbed from the gas in that time.

The remainder of the apparatus consists of a standard ammonia refrigerating plant of the type used in small ice plants and cold storage houses. The compressor can be

driven by any convenient power and will require about twenty-five horse power for each one million cubic feet of gas handled in twenty four hours.

A test plant consisting of a miniature model of this plant has been operated on the residue of gas from a number of plants during the past year. This plant is the size to handle about three hundred cubic feet of gas per hour. These tests have shown that in the Osage district in Oklahoma, about eight-tenths of a gallon of stable gasoline can be obtained from the residue gas of a compression plant operating at 250 pounds pressure during summer conditions, and about three-tenths of a gallon at an atmospheric temperature of forty-five degrees.

When this gasoline is placed in a vapor tension tube, unblended at the low temperature, when drawn from the plant it has a vapor tension ranging on different tests from seventeen pounds to twenty six pounds at one hundred degrees. When blended to seventy degrees B. and placed in the tube at about sixty degrees the vapor tension ranges from seven to nine pounds at one hundred degrees.

In raising the temperature of the raw products from twenty degrees to eighty degrees the evaporation loss has been consistent on the different tests. It is about thirty-five (35%) per cent. The distillation test of the weathered raw product shows a boiling point of about eighty-five degrees and an end point ranging from one hundred and sixty-five degrees to one hundred and ninety degrees.

Two plants are now operating on residue gas under this process, the results comparing closely with the information obtained by the test plant. The moderate temperatures used in this process do not present any special difficulties in operation and the apparatus used is of a standard type that has been thoroughly developed by years of use in refrigerating installations.

A modification of this system has been applied to treatment of natural gas containing about three pints per thousand cubic feet of gas, by an absorption test. This operation has been carried out at as low a pressure as thirty-eight pounds resulting in a very complete recovery. This work was done on an experimental plant of about two hundred and forty thousand cubic feet per twenty four hours capacity. The company which carried on this experimental work is one of the Oklahoma gas companies preparatory to the installation of a plant of this type to handle twenty million cubic feet of gas per day.

The type and operation of these plants are covered by United States patent.

The compression plant at which the refrigeration plant was installed, see Fig. 85, was compressing 800,000 cu. ft. of gas per day and showed a production of 2150 gallons of gasoline daily. The refrigeration plant increased the production 645 gallons per day. Prior to its installation a portable testing outfit was tried on the residue gas compressing it from 20 to 265 lb. and showed no gasoline.

The gasoline made in the compression plant was 76 deg. B. and that made by the refrigeration plant was 83 deg. B. after weathering, this being the gravity of the 645 gallons mentioned above which was gauged in the storage tank under 6 lb. pressure.

OPERATION OF PLANT

Compression Method Applied to Mixed Casinghead Gas—Casinghead gas varies in gasoline content from nothing up to as high as 13 gallons per 1000 cubic feet. It is commonly known to vary in different wells in the same field. The result of applying the compression method to casinghead gas taken from different wells, where the gasoline content per 1000 cu. ft. varies from two to four or more

Fig. 86—CONCRETE WATER STORAGE TANK WITH COOLING JETS

gallons, is found to be quite unsatisfactory. The production does not average up in gallons as would naturally be expected, but falls considerably below it.

The only course to pursue is to compress the different flows separately, i. e., all two gallon gas should be treated by one compression and all four gallon gas by another. In some cases the variation is not so great but should two flows of gas vary more than one gallon per 1000 cu. ft. of gas the most profitable plan to carry out is to treat them separately at the compression plant.

Condensing Pressures—While the higher the pressure of the casinghead gas the greater the amount of the gasoline obtained through proper cooling agents, it is not profitable to subject the casinghead gas to a greater pressure than three hundred pounds. Many gasoline plants operate at pressures that do not exceed 100 lbs. The reason for this is that the gasoline obtained at high pressure is of such high gravity that after it is condensed it is very difficult to keep the condensate in the liquid form. A large percentage of the higher gravity gasoline after entering the accumulator tanks re-evaporates and passes off in the residue gas which accounts for the residue gas being richer than most natural gas in heating value.

Compression and Liquefaction of the Constituents of Casinghead Gas in Plant Operation—The condensation of gasoline from natural gas is essentially a physical process. If any chemical reactions take place, they are slight, and inappreciable. G. A. Burrell tested residual gases from 10 different plant operations to determine whether carbon monoxide or olefin hydrocarbons were produced. These gases with others are found when the higher paraffins are decomposed at high temperatures and pressures in the presence of air in small quantities. Neither carbon monoxide nor olefin hydrocarbons were found.

Fig. 87

Percentage of Vapor Condensed by Compression and Cooling (from Bulletin 88, Bureau of Mines)—"The change in the raw gas that takes place in the compressors and coolers of a plant consists in the conversion of certain vapors and gases into liquid condition, and the solution of gases in these liquids. To give exact figures for the proportions of gas and vapor that disappear is impossible. An approximation, however, can be reached. One gallon of liquid pentane when converted into gas, produces about 31 cubic feet of gas at 0 deg. cent. and 760 mm. pressure. One gallon of propane in the liquid condition produces about 45 cubic feet of gas. One gallon of butane produces 37 cubic feet of gas. Butane and pentane are probably the two paraffins that are removed in greatest quantity.

Aside from such liquefaction a certain amount of gas is absorbed by the liquid, as stated above. It is small as compared to the total disappearance of gas. The authors estimate that at some plants about 35 cubic feet of gas disappears for each gallon of condensate produced from 1,000 cubic feet of gas. If 4 gallons of condensate per 1,000 cubic feet of gas is obtained, then 140 cubic feet, or about 14 per cent of the gas treated, has disappeared. At some plants, however, as much as 50 per cent of gas disappears, and at others the quantity of residual gas is almost insignificant."

Results of Analysis of Gases from Different Stages of Plant Operation—(George A. Burrell.)—"Table following shows the results of laboratory tests of various gases derived from the different stages of plant operation. The percentage of air was calculated from the oxygen content as determined by analysis.

Regarding the results shown in table on page 346, the chemical analysis, the specific gravity determination, and the claroline oil absorption show the gas represented to be a rich one. It will be seen that little difference existed between the composition of the crude gas and the same gas

Table 90

RESULTS OF LABORATORY TESTS OF SAMPLES OF GAS FROM DIFFERENT GASOLINE PLANTS

(Bureau of Mines—Paper No 88). PLANT NEAR FOLLANSBEE, W. VA.

Condition of gas	Cal. gross heating value per cu. ft. at 0° C. and 760 mm.	Specific Gravity at 0° C. and 760 mm. (air = 1.)	Proportion absorbed by 25 cc. of oil.	Composition								Remarks
				Air	CH_4	C_2H_6	C_3H_8	C_4H_{10}	N_2	CO_2	Total	
	B.t.u.			per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	
Natural gas as drawn from the well	2,544	1.46	85.7	......	......	10.8	88.3	......	0.9	.....	100	The gas was drawn from 75 producing oil wells, under a reduced pressure of 20 inches of mercury.
Residual gas after removal of 50 pounds of compression product.	2,515	1.46	......	......	......	16.9	82.9	......	0.2	.....	100	The gasoline producedwasshipped in drums to Pittsburgh, Pa., where it was blended with refinery naphtha for the market.
Residual gas after removal of 250 pounds of compression product.	2,171	1.23	78.2	......	......	59.2	40.3	......	0.5	.....	100	
Natural gas as drawn from the well	2,474	1.41	83.6	......	......	21.4	78.2	......	0.4	.....	100	These samples were taken from the same plant as those above, but were taken two months previous.
Residual gas after removal of 50 pounds of compression product.	2,415	1.38	82.0	......	......	26.5	72.4	......	1.1	.....	100	
Residual gas after removal of 250 pounds of compression product.	2,022	1.15	63.6	......	......	77.3	22.0	......	0.7	.....	100	

NOTE—This table does not apply to residue gas but to casinghead gas direct from wells.

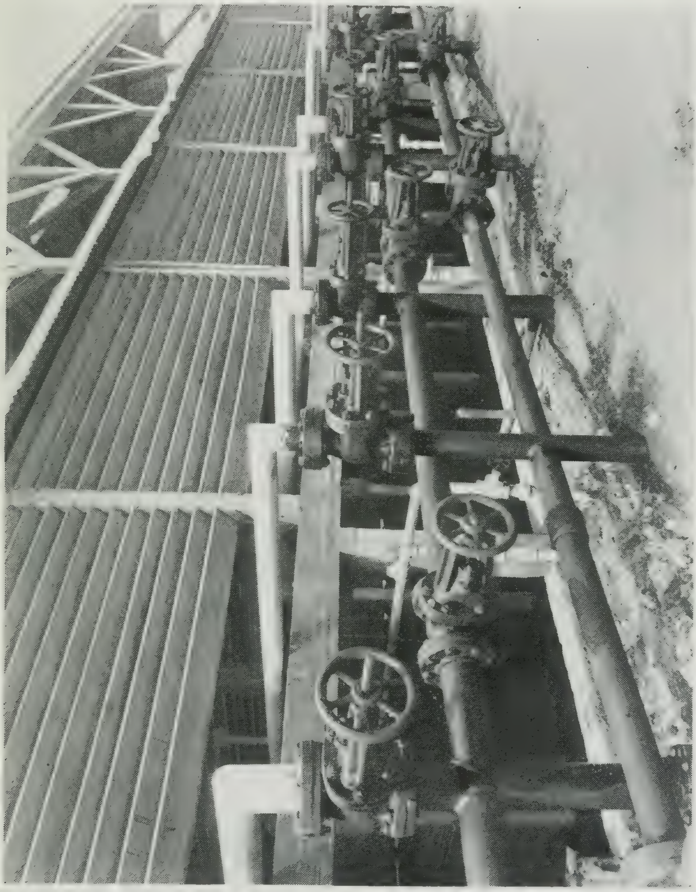


Fig. 88—MANIFOLD PIPING BETWEEN HIGH AND LOW STAGE COMPRESSORS AND ATMOSPHERIC CONDENSERS. *Drumright Plant of Tidal Refining Company*

after it had been compressed to a pressure of 50 pounds per square inch. Only after the compression to a pressure of 250 pounds per square inch and cooling, did the composition of the gas mixture change appreciably.

Under existing methods of plant operation, condensate is extracted from natural gas that ranges in specific gravity from as low as 0.8 to as high as 1.65 (air = 1), and the solubilities of the gas in claroline oil ranges from 36.9 (air free) to 85.7 per cent, according to the well from which it comes.

The authors hesitate to recommend the installation of a plant to handle natural gas that shows results as poor as the minimum values given in the table. Such gas might produce gasoline in paying quantities and might not. Probably the safest extremes would be a specific gravity of 0.85 (air = 1), and a claroline oil absorption of 35 per cent. The natural gas supplied to Pittsburgh, Pa., with which the authors are most familiar, contains little of the liquid hydrocarbons, has a specific gravity of 0.64 (air = 1), and has a claroline oil absorption of about 16 per cent. It is a dry gas and is unsuitable for gasoline production by the compression method."

Transporting Gasoline from Plant to Loading Rack—After the gasoline is blended it is stored in tanks built at a reasonable distance from the plant as a matter of safety. A pipe line is used to transport the gasoline from the storage tanks to the tank car at the loading rack. A specially designed pump is used to force the gasoline through the pipe line. Residue gas under high pressure is quite commonly used to run the pump. As these lines need not be large in size, galvanized pipe is most commonly used. The line should be buried to protect it from the heat of the sun.

It is very interesting to note the large number of loading racks, formerly used for loading oil at the nearby shipping points to some of the large oil pools, that have been changed and are now used for loading gasoline.

Compression Test Plant—By installing a small compressor and condensing coils, together with separate small sized lines leading to the various main gathering lines coming into a plant and making practical tests on samples of gas taken from these various gathering lines, the lines that are supplying gas, of high or low gasoline content can be determined.

Casinghead gas is usually found to vary in gasoline content in different sections of the fields, leases or groups of wells. With this apparatus one is able to make practical tests on gas from all the various lines leading into the plant. Should one line show two gallons of gasoline per thousand cubic feet of gas and another line show four gallons per thousand cubic feet under working conditions, it would be essential to compress the two gases separately as practice has proven that by mixing the two gallon gas with the four gallon gas an average quantity of gasoline in proportion

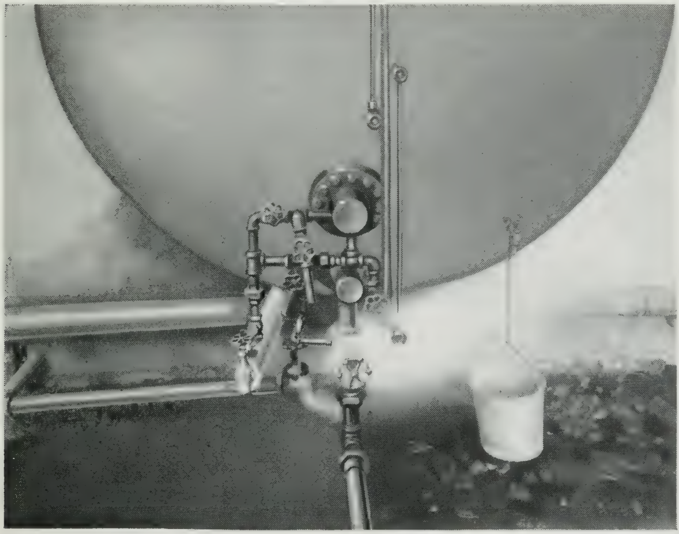


Fig. 89—ACCUMULATOR TANK
Note leaking steam around valves to prevent freezing

GASOLINE DEPARTMENT

DAILY STOCK AND OPERATION REPORT

For Day Ending 8 A. M. . ...

STOCK	STATIONS No. 1	No. 2	No. 3	No. 4	No. 5	
NAPHTHA						
On Hand 8 A. M. Yesterday						
Received						
Used						
On Hand 8 A. M. Today						
NET LOSS OR GAIN						
GASOLINE						
On Hand 8 A. M. Yesterday						
Received from Compressors						
Received from Naphtha						
Total Stocks and Receipts						
Less Shipments						
Indicated Stock on Hand						
On Hand 8 A. M. Today						
NET LOSS OR GAIN						
OPERATION						
Capacity in Cubic Feet per Day						
Cubic Feet Gas Compressed						
Raw Gasoline Made						
Raw Gasoline Made per 1000 Cubic Feet						
NAPHTHA—Received—Car, Initial and No.						
Gravity						
Temperature						
Capacity						
Outage						
Net Gallons at 60 degrees F.						
FROM						
GASOLINE—Shipped—Car, Initial and No.						
Gravity						
Temperature						
Capacity						
Outage						
Net Gallons at 60 degrees F.						
TO						

Fig. 90—DAILY STOCK AND OPERATION REPORT

GASOLINE DEPARTMENT

VACUUM PLANT No.......... DAY ENDING 7 A. M............19

Time	1 P. M.	7 P. M.	1 A. M.	7 A. M.	Average
V. P. Suction					
V. P. Discharge					
B. P. Discharge					

LUBRICATING OIL

Stock 7 A. M.	Engine	Pump
Grade of Oil		
Stock Yesterday		
Oil Received		
Total		
Oil Used		
Oil Transferred		
Difference		
Stock Today		
Loss		

OIL USED

TOUR	1		2		TOTAL	
UNIT	ENGINE	PUMP	ENGINE	PUMP	ENGINE	PUMP
1						
2						
3						
4						
5						
6						
7						
8						
Aux.Eng.						
Aux.Ma.						
Total						

ENGINE RECORD

UNIT	SHUT DOWN			CAUSE
	FROM	TO	HOURS	

REMARKS:

________________ } *Engineer* ________________ *Chief Engineer*

Fig. 91

to the volume of gas treated will not be extracted or condensed, whereas by treating them separately, i. e., separate compressor and coils, the yield of gasoline from the two gas wells treated will be greater.

Carbon Black—It is a well known fact that the residue gas coming from a gasoline plant is very high in hydrocarbons. The opportunity of making carbon black from this gas should prove to be a profitable proposition.

There are many plants from which the residue gas is allowed to go to waste into the atmosphere due to the fact that there is no market nearby. In cases of this kind the installation of a carbon black plant in conjunction with the gasoline plant ought to be a profitable proposition. On account of the residue gas or any gasoline gas being so extremely heavy it would be advisable to place the carbon making plant at a safe distance.

It requires about 1,000 cubic feet of natural gas to make one pound of carbon black. This gas referred to is a gas of about .68 gravity. No doubt it would require less than 1,000 cubic feet of the average residue gas to make one pound of carbon black.

Plants of this character require very little labor and can be run under the supervision of the regular plant foreman thus carrying little or no overhead expense.

Carbon black is mainly used in printers' ink, and is therefore a very necessary article. Every book or newspaper we read carries evidence of its usefulness.

During the European war a new use was found for carbon black. Before the war tire makers imported from Germany, oxide of zinc, which was used in the outer rubber covering of the tire to protect the rubber. It gave the tire a white color. When the importation of oxide of zinc was cut off, the tire makers on experiment found that carbon black was far superior for tires hence the black faced tire now so commonly used.

PART TWELVE

Blending

EVAPORATION LOSSES IN BLENDING—NEW BLENDING METHOD—BLENDING WITH FUEL OIL—STRAIGHT RUN GASOLINE BLEND

Blending—The gravity of gasoline may be reduced by mixing with it a quantity of lower gravity gasoline or naphtha. For instance, 50 lb. of 86 deg. gravity gasoline mixed with 50 lb. of 56 deg. gravity gasoline will give 100 lb. of approximately 71 deg. gravity gasoline. This does not, however, result in a stable mixture if left unconfined, as the lighter gravity gasoline will gradually evaporate.

METHOD OF FIGURING MIXTURES OF CERTAIN GRAVITIES TO GIVE ANOTHER GRAVITY*

Example: 60 Gravity Gasoline.
42.5 Water White.

What proportions required to make a 58 gravity of the mixture.

58	60	15.5
	42.5	2.
		17.5

1. Take 58 from 60. and set answer opposite 42.5.
2. Take 42.5 " 58. " " " " 60.

Add these two figures together and divide the answer into the top figure opposite highest gravity. This gives percentage of highest gravity fluid and the difference in percentage of 100 is the percentage of the lowest gravity fluid required. Prove same by multiplying the gravities by the percentages and adding both together.

* There is a slight approximation in this method.

58	60	15.5
	42.5	2.0

$$15.5 \div 17.5 = 88.571 \text{ per cent of 60 B.}$$
$$2.0 \div 17.5 = 11.429 \text{ per cent of 42.5 B.}$$
$$100.000$$

$$88.571 \times 60 = 53.15$$
$$11.429 \times 42.5 = 4.86$$
$$58.00 \text{ B.}$$

Evaporation Losses in Blending—(George A. Burrell)—"The following table shows the results of some blending tests made by the author. The condensate, as it was drawn from the storage tank, was allowed to stand in graduated vessels, and the loss sustained by evaporation over different periods of time was noted. The containers were graduated glass cylinders having a capacity of 1,000 cc. Their inside diameter was 2⅜ inches and they were 13 inches high. Some of the same condensate, as it was drawn from the storage tanks, was also mixed with naphtha and allowed to stand and the loss noted."

Table 91

EVAPORATION LOSSES OF DIFFERENT MIXTURES OF CASINGHEAD GAS CONDENSATES AND REFINERY NAPHTHAS

Test No.	Proportions in mixture		Specific gravity of—		Specific gravity of mixture	End of 1 hour		End of 2 hours	
	Condensate	Naphtha	Condensate	Naphtha		Specific gravity	Loss	Spdcific gravity	Loss
	per cent	per cent	deg. Baume	deg. Baume	deg. Baume	deg. Baume	per cent	deg. Baume	per cent
1	50	50	93	60	76.5	76	4	75	10
2	70	30	93	44	76	75.5	6	74.5	14
3*a*	70	30	95	44	74.5	74	13	72.5	20
4*a*	50	50	95	44	67	65.5	8	65	16

Table 91—Continued.

Test No.	End of 3 hours		End of 4 hours		Proportions in mixture		Specific gravity of—		Specific gravity of mixture
	Specific gravity	Loss	Specific gravity	Loss	Condensate	Naphtha	Condensate	Naphtha	
	deg. Baume	per cent	deg. Baume	per cent	per cent	per cent	deg. Baume	deg. Baume	deg. Baume
1......	75	12	74	16	50	50	93	60	76.5
2......	73.5	20	72.5	24	70	30	93	44	76
3*a*.....	72	26	71.5	29	70	30	95	44	74.5
4*a*.....	64	20	64	22	50	50	95	44	67

Test No.	End of 5 hours		End of 6 hours		End of 7 hours		End of 24 hours		Temperature of Atmosphere	
	Specific gravity	Loss	Specific gravity	Loss	Specific gravity	Loss	Specific gravity	Loss		
	deg. Baume	per cent	deg. Baume	per cent	deg. Baume	per cent	deg. Baume	per cent	deg. fahr.	deg. cent.
1....	74	18	73	22	70.5	31	67	43	65 to 70	18 to 21
2....	71.5	29	71	30	.....	.....	.....	.....	....	....
3*a*...	71	30	69	34	68.5	37	65	50	60 to 70	16 to 21
4*a*...	63	25	62	30	61	36	56	54	60 to 70	16 to 21

a In conducting this test the mixture was exposed to the atmosphere to a greater extent than in tests 1 and 2. It was poured from one vessel to another eight times, thus exposing more liquid surface to the atmosphere and causing more rapid evaporation than would have occurred if it had been allowed to remain in the same vessel all the time without disturbance.

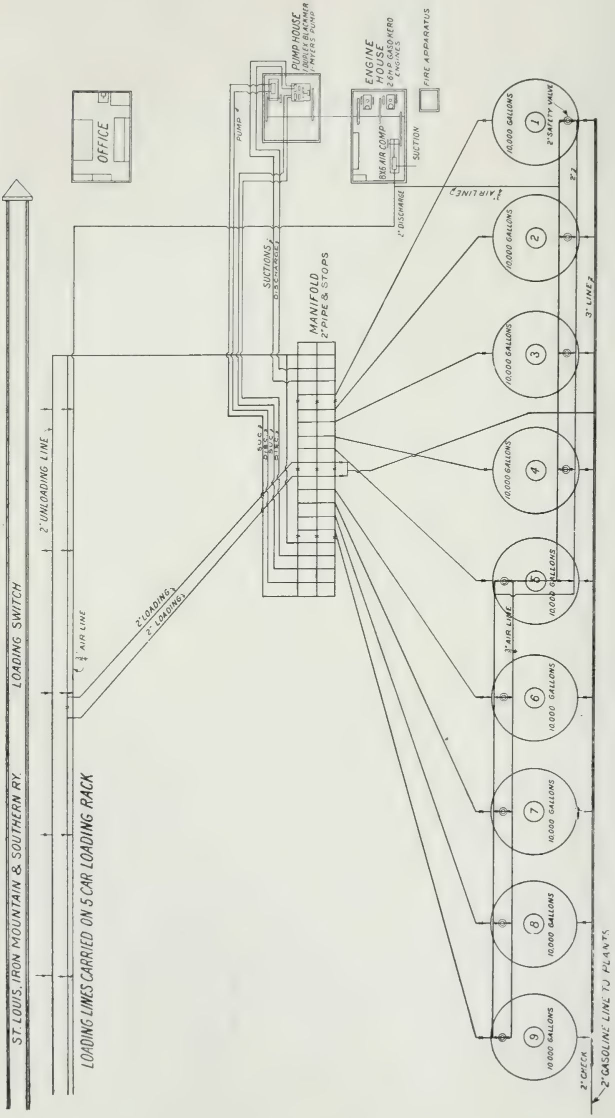


Fig. 92—PLAN OF BLENDING STATION, MANIFOLD AND LOADING RACK

NEW BLENDING METHOD*

"Casinghead manufacturers of the more forward looking type have realized for some time that the withdrawal of the Standard Oil Company of Indiana from the market for kerosene-casinghead blend precipitated a situation that necessitates a radical readjustment of the fundamentals upon which this industry has been functioning. They now see the shortsightedness of basing their business upon what proved to be only the temporary requirements of one purchaser, even as dominating a factor as the Standard Oil Company of Indiana.

By careful study of the situation and many experiments, several of these leading casinghead manufacturers have decided that the solution lies in a close linking up of the refinery with the casinghead plant, a refinery operated with the chief aim of providing suitable blending material, and the blending of the casinghead gasoline with a straight-run gasoline.

Research and experiments have demonstrated to these companies that the casinghead-straight run gasoline blend is far superior to the casinghead-kerosene blend, which has proven unsatisfactory to the consumer and to the casinghead-naphtha blend which for some years has been marketed through the jobber with success, as a motor fuel. This blend it is now impossible to make in quantity because of the scarcity of naphtha, due to the fact that the refiner, urged by the demand for gasoline is making a deeper gasoline cut in his crude.

In the early days of the casinghead industry it was discovered that casinghead gasoline in the raw state was not serviceable as motor fuel and several of the pioneer manufacturers developed the idea of blending their product with

* By J. B. Gambrell, Jr.

naphtha which enabled them to market their product direct to the jobber. This practice proved to be the first successful utilization of casinghead gasoline as a motor fuel.

With the development of the cracking process by the Standard Oil Company of Indiana, they commenced to use large quantities of casinghead in conjunction with their refinery products.

However, shipping casinghead in the raw state had a number of disadvantages which the Standard overcame by buying it in a kerosene blend and for several years they redistilled a large part of this kerosene blend directly in their pressure stills in connection with the regular cracking of gas oils.

Blending With Fuel Oil—A further extension of the same principle involved the blending of casinghead with fuel oil and shipping the blended product to refineries for rerunning. This enabled the refinery, in addition to transporting their casinghead under fairly advantageous conditions, to treat the fuel oil more or less as a heavy crude by running it down to at least a very heavy residue and extracting therefrom the lubricating oils and waxes (as well as gas oils suitable for cracking) which the skimming plant was unable to take out.

During the time that kerosene and fuel oil blends were being taken by the Standard, a considerable quantity of casinghead was also being blended with naphtha and marketed to the trade.

Most of the large Independent refiners having casinghead production, long ago adopted and followed the policy of marketing practically all of their casinghead product with straight run gasoline. Of course, the production of casinghead by these companies was but a slight per cent of the amount of straight run refinery gasoline manufactured by them and the use of casinghead gasoline was more or less incidental.

From early summer, 1919, the Standard, which was practically the only large purchaser of kerosene and fuel oil blends for re-running, began to take these products in smaller quantities and about November, 1919, made the definite announcement that they were no longer in the market for these blends. At that time, although practically out of the market, they issued to the trade a new set of specifications up to which all raw casinghead gasoline must measure.

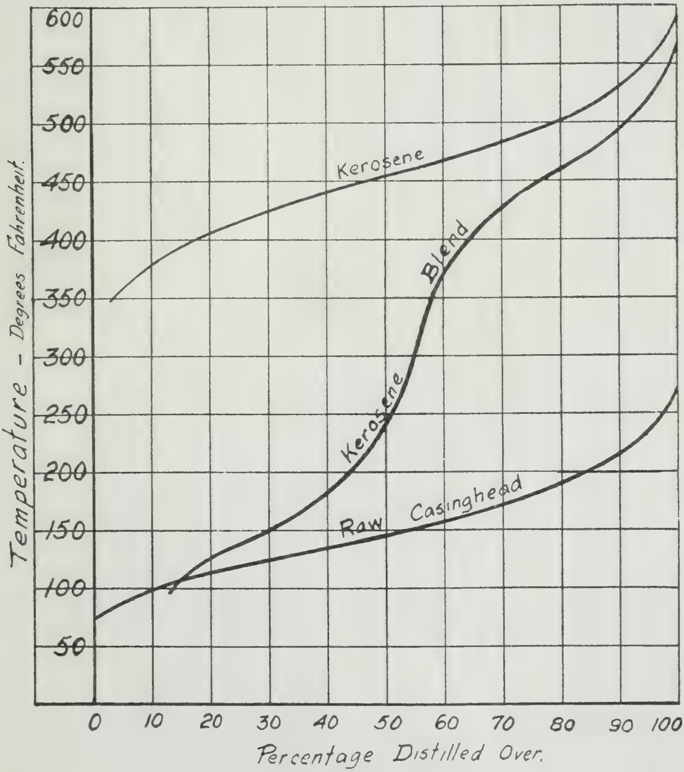


Fig. 93—KEROSENE BLEND

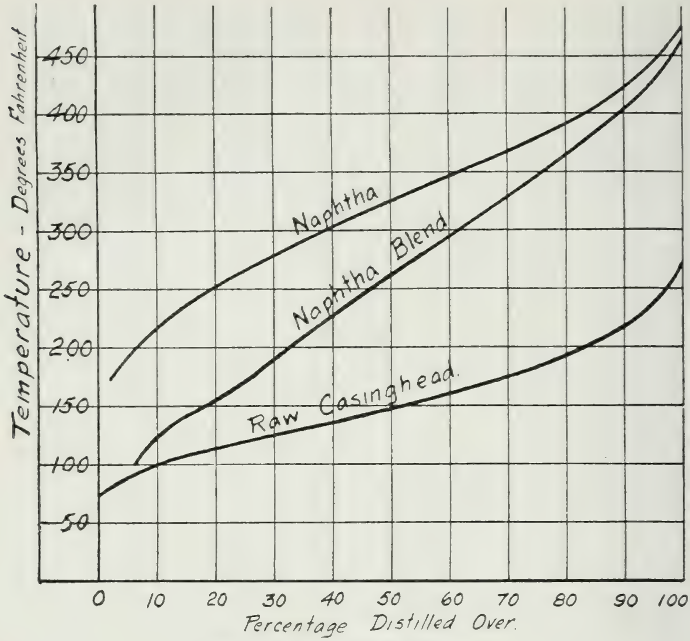


Fig. 94—NAPHTHA BLEND

They further announced that any casinghead gasoline purchased by them would be at the current market price for raw casinghead and would not be determined by the price of gasoline as shown by the Chicago tank wagon market. This stand, taken by the Standard, placed the casinghead manufacturer where he was forced to take, roughly, 14 to 17 cents for his product where heretofore, by blending, he had been able to get practically the Chicago tank wagon price for his casinghead gasoline and in many cases, a higher price.

California Market Impractical—The withdrawal of the chief purchaser of these blends left the casinghead manufacturer who had been disposing of his product through this channel, practically without a market and with but scant

facilities for establishing one. The manufacturer, with no marketing organization whatever, cast about for an outlet for his product. In several instances it was undertaken to market the raw product in California, but the great outage and excessive freight rates prevented it from becoming a commercial success.

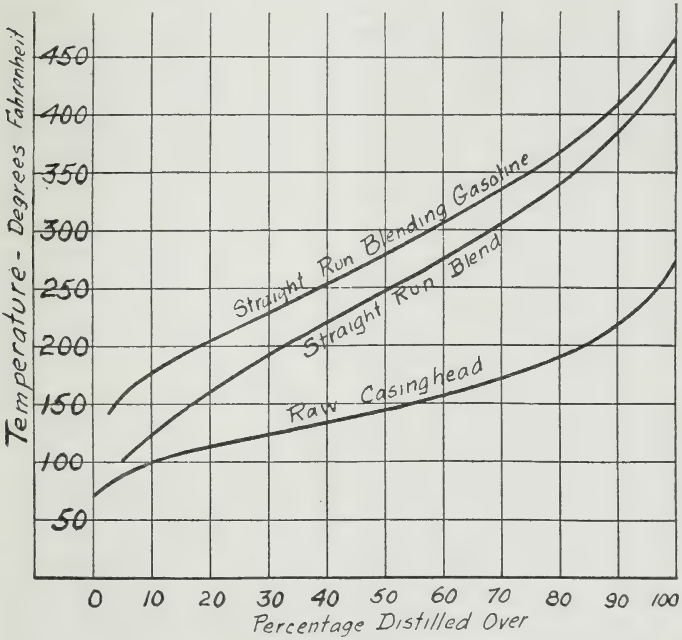


Fig. 95—STRAIGHT RUN BLEND

Such manufacturers as were fortunate enough to obtain it, blended their product with naphtha, but the demand for this product shortly made it extremely scarce and correspondingly high priced. Others undertook to market the kerosene blend to the jobbers as a straight motor fuel, but this blend failed to successfully compete with straight run gasoline and resulted in more or less complaint from the consumer.

Among the larger producers of casinghead gasoline in the Mid-Continent field is the Tidal Gasoline Company, subsidiary of the Tidal Oil Company, which in turn is the producing subsidiary of the Tide Water Oil Company. The Tidal, had to a very great extent, disposed of its product in the form of heavy blends through the channel mentioned above and was, therefore, in the same position as the majority of the casinghead manufacturers. A survey of the requirements of the consumer, the characteristics of casinghead gasoline, and the available blending material, convinced the management that a drastic readjustment of the fundamentals under which the industry had been functioning was necessary under the new conditions.

The results of this survey by the management of the Tidal Gasoline Company may be summarized as follows:

1. That the casinghead industry could not depend for their outlet upon the market created by a few large refining companies.

2. That marketing of the raw product as such to jobbers and distributors with the idea of the latter blending it was obviously impractical, as the average jobber had neither adequate facilities nor experience for properly blending this product. The element of danger in handling raw casinghead indiscriminately also constituted a serious drawback to this method of distribution.

3. That fuel oil blend was out of the question as not being a finished product but merely a means of transportation.

4. That experience in marketing the product as a kerosene blend had proven more or less unsatisfactory to the consumer and could not be relied upon for building up a satisfactory and permanent trade relationship.

5. That the ordinary naphtha blend, although more satisfactory than kerosene blend and fairly usable as a motor fuel, still had some disadvantages when compared with

straight run gasoline. The difference in distillation characterists between the ordinary naphtha and casinghead gasoline was too great to make as homogeneous a product as straight run gasoline, and homogeneity is an essential characteristic of the ideal motor fuel. This lack of homogeneity aggravated by the necessity of adding large proportions of casinghead to a comparatively heavy gravity naphtha also increased losses in transportation and in the storage tanks of the jobbers and retailers.

Straight Run Gasoline Blend—With the foregoing in mind, it became apparent that some other method must be devised for the successful utilization of raw casinghead. It was decided, therefore, that instead of blending the casinghead gasoline with some refinery by-product it should be added to straight run gasoline in the proper proportion to preserve the essential distillation requirements of an ideal motor fuel.

The accompanying charts are representative examples of the hundreds of distillation tests made in working out the problem. Each curve is the plotted result of an actual distillation test made by practical men of the Tidal Gasoline organization for the **National Petroleum News.**

Fig. 93, "Kerosene Blend." This shows the curves for the kerosene and the raw casinghead, as well as the blended product. In this and the following charts, the curve for the raw casinghead has been expanded to cover the full 100 per cent for purposes of better comparison. The distillation of the raw casinghead actually showed a loss of 24 per cent, which is not unusual.

It will be noted that the temperature equivalent to the end point of the casinghead is reached on the curve of the blended material considerably before the initial boiling point of the kerosene. The result of such extreme divergence between the products is characteristically shown in the curve of the blend. The first part of the curve indicates that the

casinghead practically all evaporated at its own normal boiling point and only after a very abrupt rise in temperature does any appreciable percentage of the kerosene boil off.

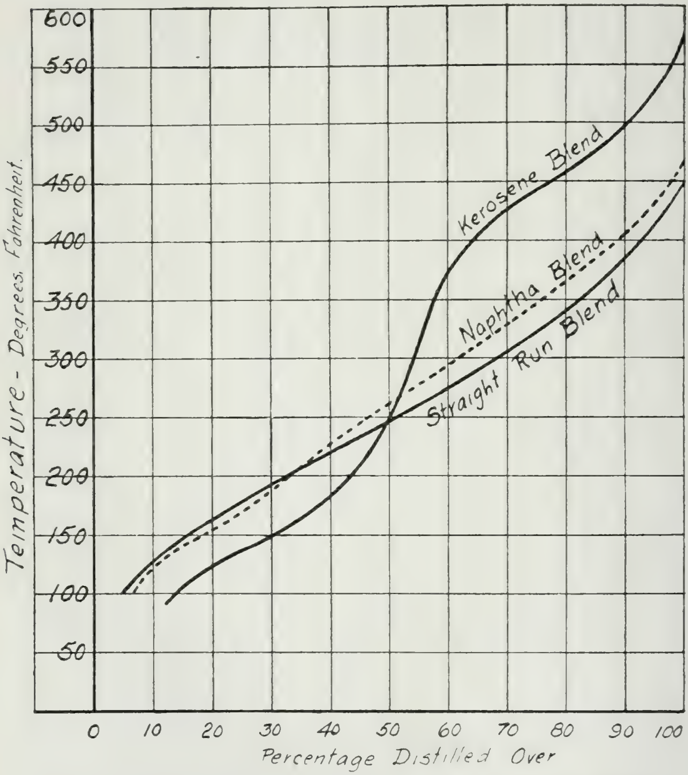


Fig. 96—COMPARISON OF KEROSENE AND NAPHTHA BLENDS WITH STRAIGHT RUN BLEND

This substantiates the experience had in loading, shipping, storing and using such a product. The manufacturer has often felt that claims of outage made by consignees have been excessive and unfair, but he was in no position to dispute them, knowing as he did, the volatile nature of a large per-

centage of the product. This, coupled with complaints from, and dissatisfaction on the part of the user, due to unsatisfactory vaporization in the carburetor and losses by evaporation, leaving a heavy residue in the feed tank, makes it impractical to consider this a satisfactory and consistent fuel for passenger cars.

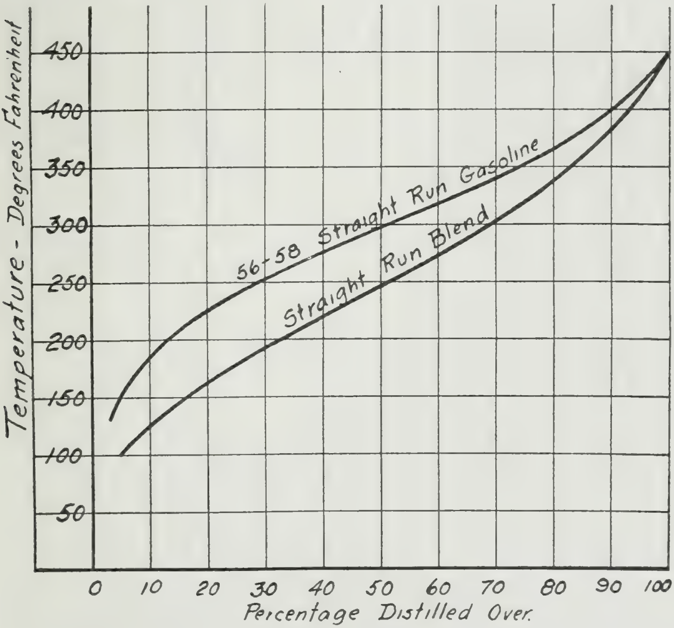


Fig. 97—COMPARSION OF STRAIGHT RUN BLEND WITH 56-58 STRAIGHT RUN GASOLINE.

Fig. 94, "Naphtha Blend." The curve of this blended product shows a great improvement over that of the kerosene and results in a reasonably satisfactory motor fuel. In comparison with an ideal curve, however, this still leaves something to be desired. The proportion of intermediates, that is to say the percentage boiling between 200 temperature and 350, is somewhat smaller than is desirable. This, of

course, is quite to be expected, inasmuch as naphtha is really a refinery by-product of the manufacture of straight run gasoline and kerosene. A greater drawback to the general use of naphtha as a blending material, however, is the lack of dependable supply. With the comparatively higher end points at which straight run gasoline is being manufactured, the available naphtha content of crude oil has been cut to such a degree that there is not nearly enough to be had for the large quantity of casinghead gasoline being recovered today. It is very apparent that the constantly increasing output of casinghead and the constantly decreasing production of naphtha will make this source of blending material less dependable from year to year.

Fig. 95, "Straight Run Blend." The blending material used in this case was a specially distilled straight run gasoline of 55 degrees gravity, obtained from the Tidal Gasoline Refinery No. 2. The average boiling points are somewhat higher than the general run of 56-58 gasoline being marketed by the Independent refiners of the Mid-Continent field. This was blended to 60-61 gravity in the proportions of approximately 75 per cent of blending material and 25 per cent of casinghead. The resulting distillation curve shows what is believed to be an ideal motor fuel. The initial is low enough for all practical purposes for any season of the year and in any climate. The percentage of intermediates is such as to insure uniformity of carburetion, an essential to a smooth running motor, while the higher fractions are sufficient to insure maximum power without an accompanying deposit of carbon. The homogeneous blending of the light fractions of the gasoline blending material with the casinghead prevents undue losses by evaporation, excessive vapor tension, and precludes the possibility of separation between fractions. The available supply of such a blending material is limited only by the crude in the field and the refining capacity of the territory.

Fig. 96, "Comparison of Kerosene and Naphtha Blends with 'Straight Run Blend.'" This chart shows graphically the differences in the characteristics of the curves of the various blends described in the previous three charts.

Fig. 97, "Comparison of 'Straight Run Blend' with Straight Run 56-58 Gasoline." The two curves on this chart show a comparison of the straight run blend (Fig. 95) with 56-58 gasoline, the latter representing the bulk of the gasoline output of the Mid-Continent refineries. As shown by these two curves, the better quality for practically all conditions of the blended gasoline over the 56-58 straight run is quite apparent. The lower initial boiling point, the greater percentage of intermediates and the lesser proportions of high-boiling point hydro-carbons in the blended product indicate its superiority over the 56-58 gasoline. Incidentally the addition of casinghead gasoline to a straight run gasoline results in the intermingling of functions of each of the two products which are very closely related in their general characteristics, a considerable part of the distillation curve of each overlapping the other. This results in a more homogeneous motor fuel than is possible by blending the casinghead with naphtha or any other heavier fraction of crude oil.

The Tidal Gasoline Company realized that with its large output, it would be impossible to attain this ideal and to continuously market a uniform product unless the manufacturer of the blending material were under its control. If this blending material were secured from other refinery organizations which did not have in mind the problems confronting the casinghead manufacturer and to whom the output of this blending material would be but incidental to their main operations, the quality of the production turned out by the refiner would be affected by the exigencies of his particular case rather than the requirements of the casinghead manufacturer. This would make it extremely difficult, if not en-

tirely impossible, to continuously market a uniform product which would insure satisfaction to the consumer and the distributor and thereby make for satisfactory and permanent trade relationships, as well as insure a steady and dependable outlet.

Linking Up Refining Industry—With all these points in mind, the Tidal Gasoline Company decided that the only practical solution was the building and operating of its own refineries. In the carrying out of this policy, this company has leased and is now operating a refinery at West Tulsa which furnishes part of its straight run blending material requirements. Exhaustive research work and practical tests are being carried on with the straight run blending gasoline being obtained by this combination and the knowledge and experience so developed is being utilized in the finishing of a 3,000 barrel refinery which is under construction and will be ready for operation in the near future at Drumright, Oklahoma. This new refinery is located on the same site as their large casinghead gasoline plant and will be operated as an adjunct to it.

This change, which has been brought about in the casinghead industry within the last year, is made particularly significant by the fact that the Tidewater Oil Company, with its well known conservative policies, and which up to this time has confined its refining operations to the Atlantic seaboard, is the first, through its subsidiary, the Tidal Gasoline Company, to undertake the operation of refineries for the sole purpose of providing a satisfactory blending material for its casinghead production. This action by the Tidewater organization presages a new era in the development of the casinghead industry, which, up to this time, due to its rapid growth, has been in a more or less formative or undeveloped stage.

It is believed that this move is the forerunner of what may be termed the "combination" or "consolidation" period and will result in the ultimate stabilization of the industry."

PART THIRTEEN

Absorption Plant*

OIL ABSORPTION PROCESS—GASOLINE EXTRACTION AND HEATING VALUE OF GAS—CHARCOAL ABSORPTION PROCESS.

The absorption process for the extraction of gasoline from "lean" natural gas has assumed commercial importance as the demand for gasoline has increased. When one considers the tremendous demand today it hardly seems possible that only about thirty years ago a patent was issued in this country (See U. S. Patent No. 342,564 to Benton, issued May 25th, 1886), whose primary object was to avoid the production of benzine from crude oil and to increase the yield of illuminating oil.

The first patent of note, which embodies all the essentials of natural gas absorption process was the British Patent No. 3137 to William Young, of Clippens, issued in 1874. This patent, which covers the extraction of gasoline from gas derived from the distillation of shale, did not come into use in this country until the development of the automobile industry so increased the demand for gasoline as to lead to the development of this process in an absorption plant at Hastings, W. Va.

In all the essential features the absorption of gasoline from "lean" natural gas is identical with the extraction of benzol, toluol and other allied products from gas made by the destructive distillation of coal, with the extraction of gasoline from gas resulting from the distillation of shale, and extraction of gasoline from gas evolved in the cracking distillation of heavy oil.

* The Author is especially indebted to P. M. Biddison and H. T. Boyd for the data.

Under similar conditions of temperature and, if necessary, pressure to attain this temperature, the gas resulting from the decomposition or destructive distillation of vegetable matter, coal, oil or shale, resulting in the formation of so called natural gas, coal gas, oil gas, or shale gas, shows almost identical percentages of the main hydrocarbon constituents.

Hence, any patent, such as Youngs, applicable to the absorption of a hydrocarbon mixture (gasoline) from shale gas is applicable to the absorption of hydrocarbons from coal gas, natural gas or oil gas. The fact that the absorption of gasoline from natural gas is ordinarily carried out under the relatively high pressure necessary to affect transportation, while the absorption of aromatic and paraffin hydrocarbons from coal gas, or gasoline from shale gas is ordinarily carried out under relatively low pressure, does not indicate that in the case of natural gas there exists a certain critical pressure above or below which the extraction cannot be carried out commercially. The fact that there are today commercial gasoline absorption plants operating in this country at relatively low pressures, below 30 lb., proves that such a critical point does not exist.

The pressure on the natural gas is due to either natural rock pressure or artificial pressure to affect transportation. Since natural gas follows closely Henry's law, which states that the volume of gas which a given menstrum will absorb is directly proportional to the pressure, it naturally follows that wherever possible, the absorption is carried out under pressure, since as a result of Henry's law, under high pressure a smaller volume of the absorbing menstrum secures the same yield as a larger volume at low pressure, thus materially reducing the size of the plant required to handle the same volume of gas.

The application of the principle of absorption to natural gas was delayed, not to the fact that the principle was not

known, but to the fact that the demand for gasoline did not assume proportions warranting the expense of absorption installations until the advent of the automobile industry about 1900 and the consequent tremendous increase in the demand and rise in price of gasoline.

In the absorption process, whether applied to coal gas, shale gas, natural gas, or oil gas, the typical counter current method is followed out, that is, the gas leaving the absorbers meets pure solvent while the rich gas entering the absorbers meets enriched solvent. The absorbing menstrum is in most cases a petroleum distillate of about 35 deg. Baume or a coal tar distillate such as creosote.

After the liquid has been removed from the gas, the enriched oil is sent to a steam still where a separation is affected. The process is continuous in that the absorbing menstrum is used over and over again. This absorption process has been in use for many years. As is natural, many different types of absorbers, steam stills, and different conditions of temperature were and are employed.

There might also be mentioned a process in vogue for a number of years past and practiced at some refineries, of subjecting uncondensed gas or petroleum vapors to absorption in naphtha, whereby the claim is made that the gasoline yield is increased considerably. At the present time attention is drawn to the use of the absorption product itself as the absorption menstrum, employing it at low temperatures. Although claims are made that the yield is thereby increased, sufficient data is not at hand to determine the commercial application of the process.

Numerous tests have been conducted on an experimental plant designed in strict accordance with the British Patent issued to Young in 1874. The results attained were very gratifying. A yield on a so-called "dry" natural gas of 1.2 pints per thousand cubic feet of gas was obtained of water white commercial gasoline having a gravity of about

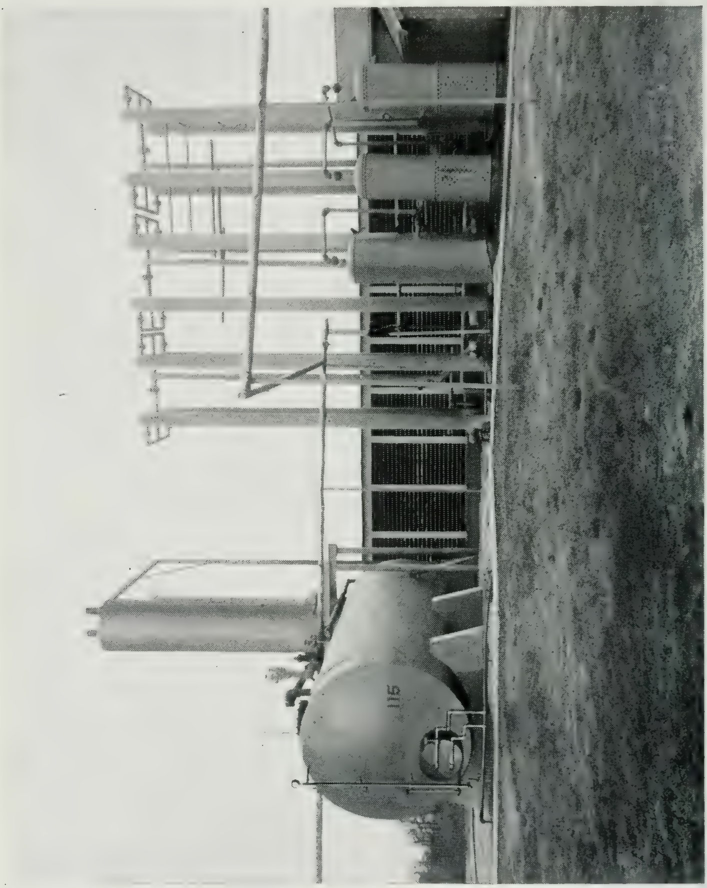


Fig. 98—AN ABSORPTION PLANT

75 deg. Baume. The plant operated 100 per cent efficient against a large absorption plant, with a capacity 50,000,000 cubic feet of gas per day, operating on the same gas.

The first large absorption plant in this country for extracting gasoline from natural gas by the absorption method was built at Hastings, W. Va., after extensive experiments by G. M. Saybolt, of the operating company. The plant began operation in 1913. The process consists in causing the natural gas to bubble up through a petroleum distillate of about 35 deg. Baume gravity at high pressure. The enriched oil is then sent to a steam still to separate the gasoline and after separation the absorbing menstrum is used over and over again. The gas is passed through the absorbing oil at the high pressure used to affect transportation. The hot oil from the stills is cooled in a double pipe cooler or heat exchanger by the cold oil enroute to the still from the absorber and is further cooled, before reaching the absorbers, by passing through pipe coolers on which running water falls. The general process is identical with the process of absorbing light oil from coke oven gas and the process covered by British patent to Young, No. 3137, issued in 1874, covering the extraction of gasoline from shale gas.* A patent covering the application of the absorption process as applied to natural gas, when operating at pressures in excess of 30 pounds, was granted to Geo. M. Saybolt, in 1911. This is U. S. Patent No. 989,927. Since copies are readily obtainable from the Patent office it is not reprinted here.

DESCRIPTION OF THE ABSORPTION PROCESS

Figure 99, Page 375, shows the scheme of the absorption process as generally applied to the extraction of gasoline from natural gas. The arrangement and type of apparatus is of course subject to many variations.

Natural gas from the transmission line at a pressure which may vary from atmospheric pressure to several hun-

* See Bulletin 120—Bureau of Mines.

dred pounds, enters the absorber A, through the pipe B. This absorber consists of a vertical cylindrical shell partially filled with broken stone, brick, building tile or any other material that will make a porous filling and expose a large amount of surface. This filling rests upon the grating C. Gas entering through the pipe B, passes upward through the absorber and leaves the absorber through pipe D, through which it is delivered to the market. Oil enters the absorber through the pipe E, and passes downward through the porous filling, absorbing gasoline as it trickles down through the filling. The oil is kept continuously drawn off from the bottom of the absorber by the trap F, which automatically dumps oil containing gasoline into the vent tank G. Thus the oil level in the absorber A, never reaches a level more than a few inches higher than the oil outlet pipe H, and never, except in case of the trap F failing to work, reaches the level of the pipe B, so that in this absorber gas does not bubble up through a pool of oil.

In the vent tank G, the pressure is maintained at from 2 lb. to 5 lb., the safety valve allowing gas to escape to the atmosphere should 5 lb. pressure be exceeded, and the check pressure regulator, through which the vapors given off in this tank normally escape, maintaining continuously a pressure in excess of 2 lb. in this tank. Due to the reduction of pressure on the oil upon being released from the absorber into the vent tank, some of the lighter constituents which had been absorbed by the oil vaporize. These vapors pass out through the vapor line I, to the compressor J, where they are compressed either in one or two stages, cooled in the cooler K, and delivered to the accumulator tank L.

In the condenser K, some of the heavier constituents are liquefied due to the increase in pressure and reduction of temperature. These liquids separate in the accumulator tank L, and are delivered through the trap M, to the running tank N, while the uncondensed gas leaves the accumulator

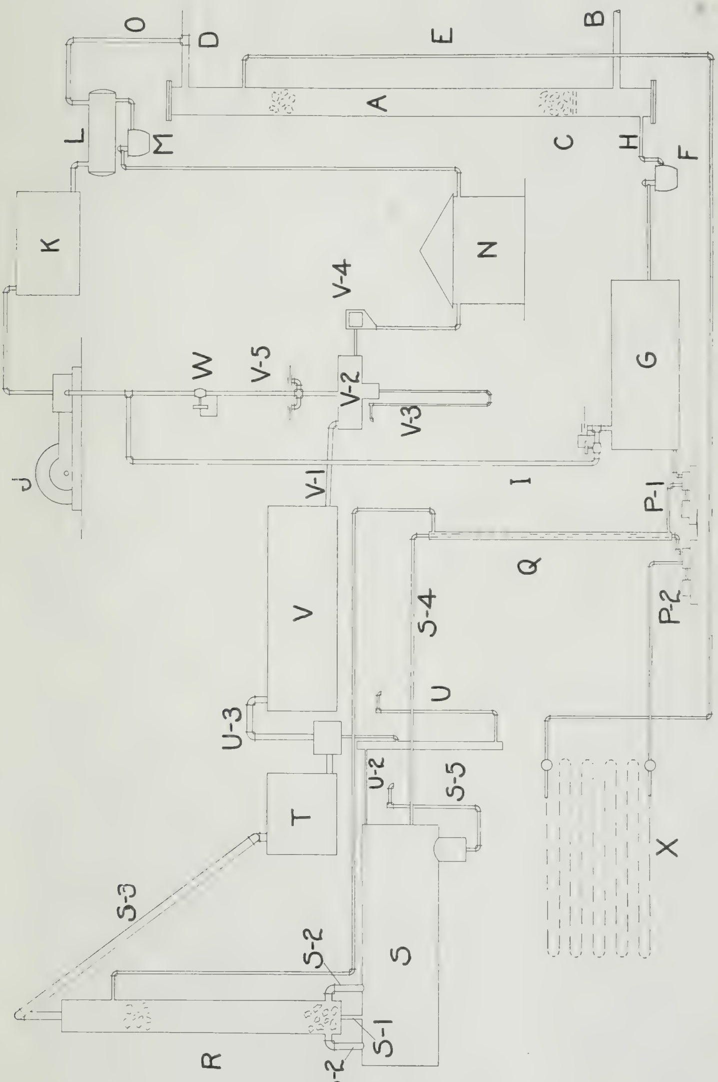


Fig. 99—DIAGRAM OF AN ABSORPTION PLANT

tank through the pipe O, and is delivered into the transportation line through pipe D, along with the other treated gases.

The oil from vent tank G is continuously pumped by means of the oil pump P-1 through the exchanger Q, where it is heated to some extent by hot oil coming from the still, to the upper portion of the stone tower R which sets above the still. This stone tower is filled with some porous substance in the same manner as the absorber. The charged oil entering at the upper portion trickles down over the porous filling and enters the still through the pipe S-1. In the still S are steam pipes, which are perforated, allowing either high pressure live steam or exhaust steam to be sprayed into the body of oil in this still. The heat contained in this steam heats the oil in the still to a point sufficient to vaporize the gasoline contained in the oil. These vapors enter the stone tower through the vapor lines S-2 and ascend through the downflowing oil, leaving the stone tower through the vapor pipe S-3, entering the condenser T, where they are cooled to a temperature of about 180 deg. fahr., which results in the condensation of some water which is drawn off by the automatic siphon U, and of some absorbent oil which is returned to the still through the pipe U-2. The balance of the vapors leave the separating pot through the vapor line U-3 and enter the main condenser V, where they are cooled as low as possible with the available supply of cooling water. This cooling results in the condensation of the greater part of the vapors and these vapors and condensed gasoline leave the condenser through the pipe V-1, entering the separator V-2 where water is drawn off by the automatic siphon V-3, the gasoline passing through the look box V-4, where it may be inspected, into the running tank N. The vapors which are not condensed in the condenser V pass off from the separator V-5, through the check pressure regulator W, which mantains a pressure of about 2 in. of water

on the separator V-2, thence to the compressor J, where they are treated in the same manner as the vapors off the vent tank G.

The oil from the still S is drawn off through the pipe S-4 through the exchanger Q, imparting a portion of its heat to the charged oil going to the still from pump P-1, thence to the pump P-2, which delivers this denuded oil through the oil cooler X at a pressure sufficient to force it through the line E into the top of the absorber A, where it may again absorb gasoline from the gas to be treated, thus making a continuous circulation of the oil.

The steam which is condensed in the still S is drawn off through the automatic siphon S-5. Provision is made for the pumping into the system, either into the line E, or the still S, of whatever absorbent oil is required from time to time to make up the loss of absorbent oil.

The oil which is usually used in this system is that commonly known as Mineral Seal Oil.

Locating Plant—The location of an absorption plant will usually be determined by:

Existing pipe lines,
Pressure available,
Water supply,
Shipping facilities.

Existing Pipe Lines—These will determine the facilities for concentrating the gas for treatment at one or more locations. One large installation is much more economical and efficient than a number of small ones of equal capacity.

Pressure—The gasoline content of a gas may be completely extracted by the absorption process at any pressure above atmospheric, but the cost of the absorption installation will be greater at low pressure than at high pressures and the cost of operating will be higher at low pressures than at high pressures. Therefore, on a gas transportation system, where the pressures are fixed by the requirements of

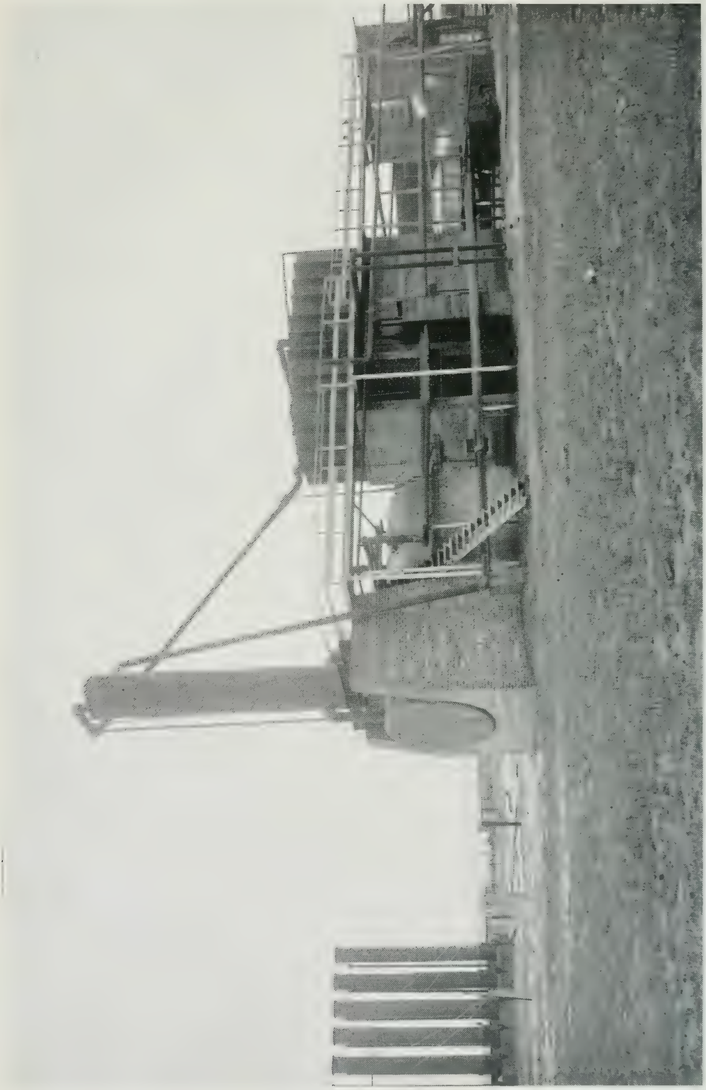


Fig. 100—ABSORPTION PLANT SHOWING ABSORBERS, STILL, ETC.

Table 92—ABSORBING OIL CIRCULATION GALLONS PER THOUSAND FEET OF GAS FOR VERTICAL COUNTER CURRENT ABSORBERS AT 65 DEG. FAHR.

Gasoline Content of gas Gallons per thousand feet.	Saturation of Absorbent Oil, per cent.										
	.218	.445	.620	.923	1.35	1.73	2.50	3.25	4.00	4.75	6.25
	Pressure-Pounds Gauge Pressure										
	0	15	30	50	75	100	150	200	250	300	400
.05	23	11	9	6	4.0	2.9	2.0	1.6	1.25	1.1	0.8
.10	46	23	16	11	7.5	5.8	4.0	3.1	2.5	2.1	1.6
.15	69	34	24	16	11.0	8.7	6.0	3.9	3.8	3.2	2.4
.20	92	45	32	22	15.0	11.6	8.0	6.2	5.0	4.2	3.2
.25	115	56	40	27	18.5	14.5	10.0	7.7	6.3	5.3	4.0
.30	137	67	48	33	22	17.3	12.0	9.2	7.5	6.3	4.8
.40	183	90	64	43	30	23	16.0	12.3	10.0	8.4	6.4
.50	229	113	80	54	37	29	20	15.4	12.5	9.5	8.0
.75	344	169	121	81	56	43	30	23	19	15.8	12
1.00	458	225	161	108	74	58	40	31	25	21	16
1.25	573	281	202	135	93	72	50	38	30	26	20
1.50	688	337	242	162	111	87	60	46	38	32	24
2.00	917	450	323	220	148	116	80	62	50	42	32

Note—The above saturation and rates of oil circulation will produce very efficient extraction. Many successful plants are operating with a saturation rate ten times as great as given above, with a consequent decrease in oil circulation required.

transportation, it will be found desirable, both from the standpoint of first cost and cost of operating, to locate the absorption plant at the high pressure end of the line. The effect of pressure on the cost of installation may be calculated from the data given on the effect of pressure on absorber capacity, oil rate, still capacity and steam required. For an absorption plant operating on casinghead gas the pressure selected should be that at which the residue gas may be returned to the lease for consumption or otherwise disposed of.

Effects of Pressure on Absorption—It has been repeatedly demonstrated that Henry's Law of Absorption of Gases by Liquids applies in regard to the effect of pressure upon the absorption of gasoline from natural gas. That is, the amount of oil required to absorb the complete gasoline content of a given gas varies inversely with the pressure, or the allowable saturation (ratio of gasoline absorbed to oil used) varies directly with the pressure. In Part 7 are given the saturation ratios allowable for use with the single coil testing absorber. Table 92 shows the oil rate adaptable to large scale vertical absorbers.

For gases richer than 1.0 gallon per thousand feet the oil rates given are higher and the saturation rates lower than would ordinarily occur in plant practice on this rich gas, where high efficiency of gas drying is not so essential to profitable operation. The figures given will produce high efficiency of extraction.

Water Supply—An ample and reliable water supply is essential. It is highly desirable to have this supply of a low temperature since low oil temperatures aid materially in reducing the oil circulation required. If recooling of the water is necessary the best type of water cooling apparatus should be selected to the end that the oil may be cooled to as low a temperature as is possible by means of such recooled water.

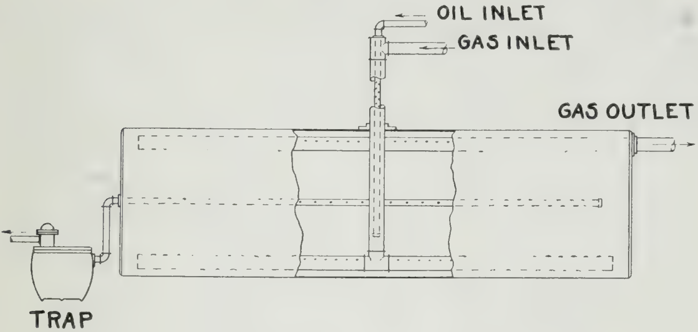


Fig. 101—HORIZONTAL ABSORBER

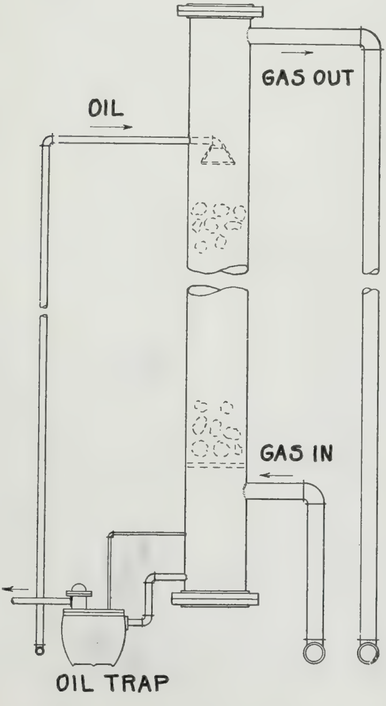


Fig. 102—VERTICAL ABSORBER

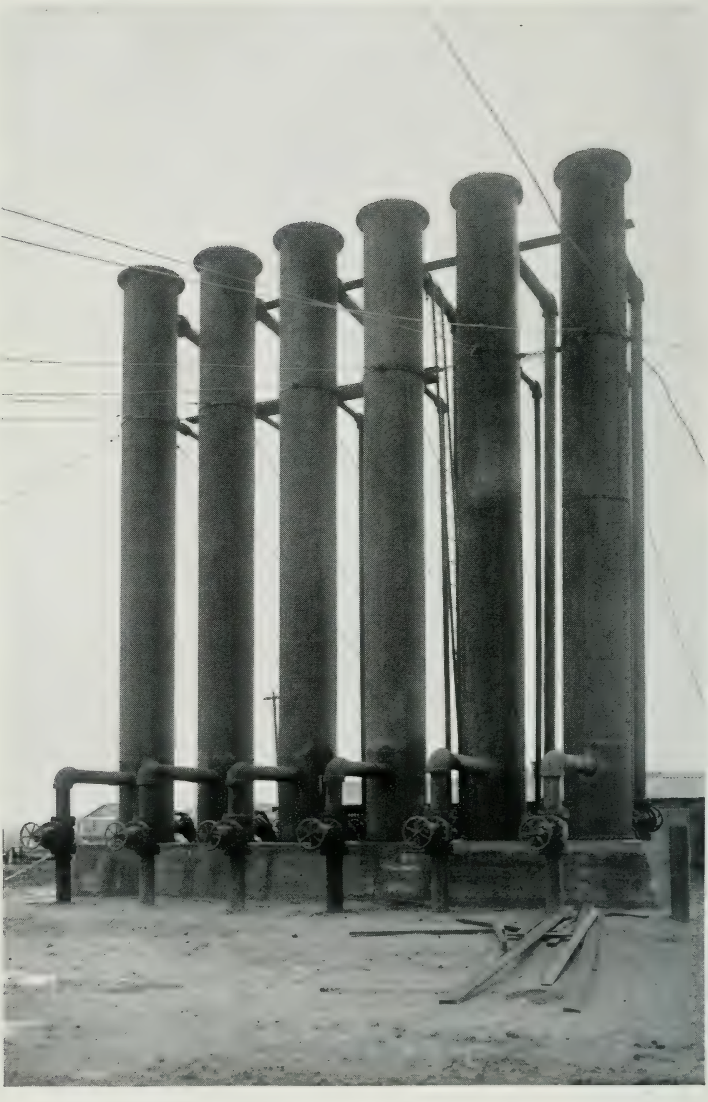


Fig. 103—VERTICAL ABSORBERS SHOWING GAS INLET

Cold water for the condenser boxes is usually of not so great importance, except in a low pressure plant. Gasoline which is not condensed in the main condenser can be obtained by compression of the tail gases and even in low pressure installations, using comparatively warm water on the condenser boxes, this can be done, if the tail gases are compressed to a high enough pressure.

Shipping Facilities—It is of course desirable to locate near a railroad, but if considerations of the other elements of location preclude this, the product may be conveniently transported by pipe line for considerable distances and with small losses. Pipe lines for such purposes should be laid with exceptional care to insure tightness. They should be buried deep to prevent heat absorption by the gasoline and consequent evaporization which causes most of the losses in piping gasoline. Shellac is recommended for joints. No difficulty need be experienced in pumping such gasoline if a pump be selected with low velocities through the parts and if the pump be located so there is always pressure on the intake. Gasoline from both compression and absorption plants is in many cases transported by pipe line for distances of from one to fifteen miles without great losses.

Design—The proportions of apparatus for an absorption plant are fixed by:

(1) The amount of gas to be treated,
(2) The pressure at which the gas is to be treated,
(3) The gasoline content of the gas,
(4) The temperature of the absorbing oil.

Absorbers—Items 1 and 2 determine the size of absorbers required.

There are two types in general use—horizontal and vertical. They are illustrated by figures 101 and 102.

The authors much prefer the vertical absorber, it having been found by experiment that for the same amount of oil circulated per thousand cubic feet of gas, the vertical

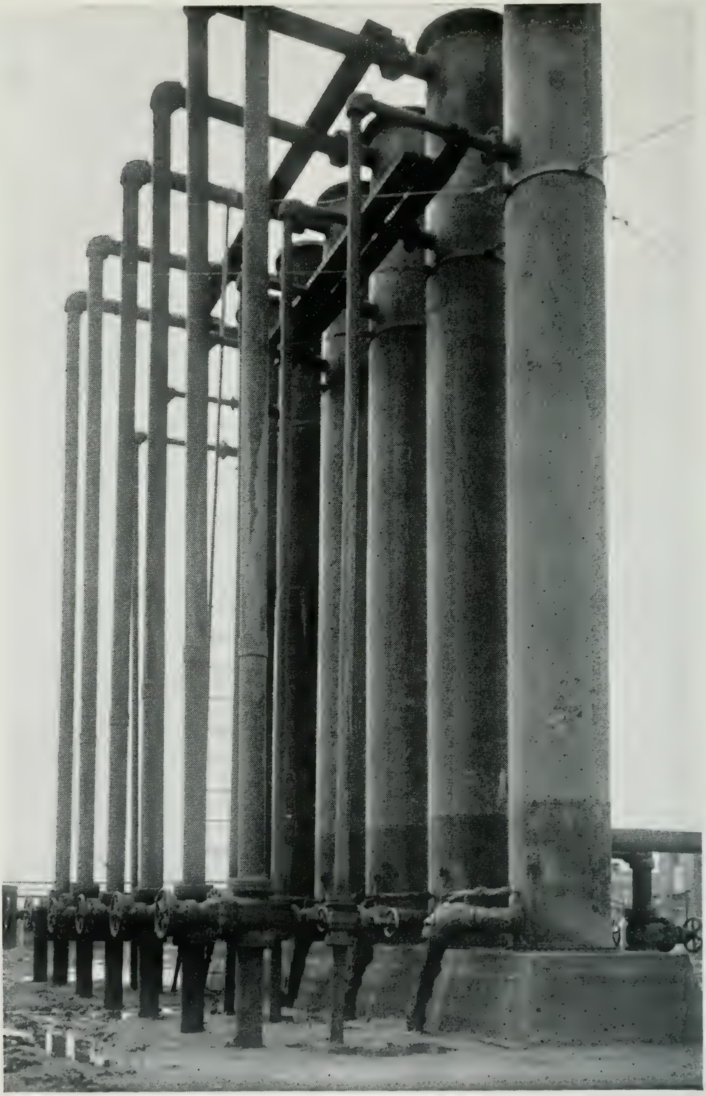


Fig. 104—VERTICAL ABSORBERS SHOWING GAS OUTLET AND OIL INLET AND OUTLET

counter current type of absorber will show more complete extraction of the gasoline content. This is due to the fact that the lean gas from the gathering lines or pumps entering the top of the absorber, comes in contact with fresh oil whose absorbing power has not yet been impaired by the absorption of gasoline.

The two types may be advantageously combined, especially for rich gas, the gas passing first through a horizontal absorber and then through a vertical absorber, while the circulation of the oil is first through the vertical absorber and then into the horizontal absorber.

For a very high efficiency of extraction without using an excessive oil circulation this will be found desirable and is practiced in some plants. The same results may be secured by using two vertical absorbers in series.

The capacity of an absorber depends upon the rate of gas flow at which the gas tends to carry oil with it in suspension or in a mist. The vertical type is usually filled with crushed hard limestone of sizes from 2½ in. to 5 in. or with hollow 4 x 5 x 6 building block. Their height should be not less than 35 feet and an added ten or fifteen feet will secure higher efficiency of extraction.

Other types of filling may be used, such as thread protectors, sheet steel cuttings, wood lattice work, etc.

The capacity* of the vertical absorbers is based upon the flow of approximately 100 feet per minute through the voids or 60 feet per minute through the open column.

For the horizontal type of absorber the capacity of the absorber may be found from the following equation:

$$Q = L \times d \times P \times 1.43.$$

When L = Length of absorber in inches.

d = Diameter of absorber in inches.

P = Absolute pressure (gauge pressure plus 14.4).

* Revised by author.

From these formulae, tables of capacity have been computed and are shown on pages 387 to 390, Tables 93 to 96.

When a horizontal absorber and a vertical absorber are used in series, the gas entering the horizontal absorbers first, twice the capacities of horizontal absorbers given in Table 93, may be used, but the capacities given in Table 96 for vertical absorbers must not be exceeded.

Oil Traps—To continually draw off the saturated oil from the absorbers while preventing the escape of gas, traps of similar construction to steam traps are used. These may be either of the float type with continuous discharges or the bucket type with intermittent discharge, but either must be designed for the pressure under which the absorber will operate and for the class of oil used as the absorbent. Since "Mineral Seal" oil is lighter than water, about .82 specific gravity, the leverage available to operate the valve mechanism is not the same as when the trap is used on water and different ratios of valve area to float or bucket area are required from those applying to water. The C. E. Squires Co., Ohio Blower Co. (Swartout), American Steam Gauge and Valve Co., and Strong Carlisle and Hammond Co. have supplied traps especially designed for this class of work. Figs. 105 and 107 illustrate traps of the bucket type adapted to this work. Table 97 gives the capacities of Strong traps on Mineral Seal Oil.

Other manufacturers will furnish similar data on traps for this purpose upon request. It is not to be inferred that all traps of the same pipe connection sizes will have the same capacity.

The capacity of traps to be used can be determined from the amount of oil to be circulated which is discussed under "Effects of Pressure" on page 380. It is advisable to have one trap for each absorber.

Table 93—HORIZONTAL ABSORBERS. LENGTH IN FEET REQUIRED PER MILLION CUBIC FEET OF GAS.

Diameter of Absorber Inches	Gauge Pressure in Pounds per Square Inch														
	0	25	50	75	100	125	150	175	200	225	250	300	350	400	500
8	506	185	113	81.7	63.8	52.3	44.2	38.5	34.0	30.5	27.5	23.1	20.0	17.5	14.2
10	405	148	90.4	65.3	51.0	41.8	35.4	30.8	27.2	24.4	22.0	18.5	16.0	14.0	11.3
12	337	123	75.3	54.4	42.5	34.8	29.5	25.7	22.7	20.3	18.3	15.4	13.3	11.7	9.4
14	289	106	64.5	46.6	36.4	29.8	25.3	22.0	19.4	17.4	15.7	13.2	11.4	10.0	8.1
16	253	92.5	56.5	40.8	31.9	26.1	22.1	19.3	17.0	15.3	13.8	11.6	10.0	8.8	7.1
18	225	82.1	50.2	36.2	28.3	23.2	19.6	17.1	15.1	13.5	12.2	10.3	8.9	7.8	6.3
20	200	74.0	45.2	32.7	25.5	20.9	17.7	15.4	13.6	12.2	11.0	9.3	8.0	7.0	5.7
24	169	61.7	37.7	27.2	21.3	17.4	14.8	12.8	11.3	10.2	9.2	7.7	6.7	5.8	4.7
30	135	49.3	30.1	21.7	17.0	13.9	11.8	10.3	9.1	8.1	7.3	6.2	5.3	4.7	3.8
36	113	41.1	25.1	18.2	14.2	11.6	9.8	8.6	7.6	6.8	6.1	5.1	4.4	3.9	3.1
42	96	35.2	21.5	15.5	12.1	9.9	8.4	7.3	6.5	5.8	5.2	4.4	3.8	3.3	2.7
48	84	30.8	18.8	13.6	10.6	8.7	7.4	6.4	5.7	5.1	4.6	3.8	3.3	2.9	2.4
60	68	24.7	15.1	10.9	8.5	7.0	5.9	5.1	4.5	4.1	3.7	3.1	2.7	2.3	1.9
72	56	20.6	12.6	9.1	7.1	5.8	4.9	4.3	3.8	3.4	3.1	2.6	2.2	1.9	1.6
84	48	17.6	10.8	7.8	6.1	5.0	4.2	3.7	3.2	2.9	2.6	2.2	1.9	1.7	1.3
96	42	15.3	9.4	6.8	5.3	4.3	3.7	3.2	2.8	2.5	2.3	1.9	1.7	1.5	1.2

Table 94—HORIZONTAL ABSORBERS, CAPACITY IN THOUSANDS OF CUBIC FEET PER 24 HOURS, PER FOOT OF LENGTH

Pressure in Lb.		Diameter of Absorber							
Gauge	Absolute	8 in.	10 in.	12 in.	14 in.	16 in.	18 in.	20 in.	24 in.
0	14.4	1.976	2.47	2.964	3.458	3.952	4.446	5	5.928
25	39.4	5.408	6.76	8.112	9.464	10.816	12.168	14	16.224
50	64.4	8.816	11.02	13.224	15.428	17.632	19.836	22	26.448
75	89.4	12.240	15.30	18.360	21.420	24.480	27.540	31	36.720
100	114.4	15.616	19.52	23.424	27.328	31.232	35.136	39	46.848
125	139.4	19.120	23.90	28.680	33.460	38.240	43.020	48	57.360
150	164.4	22.560	28.20	33.840	39.480	45.120	50.760	56	68.680
175	189.4	26.000	32.50	39.000	45.500	52.000	58.500	65	78.000
200	214.4	29.440	36.80	44.160	51.520	58.880	66.240	73	88.320
225	239.4	32.800	41.00	49.200	57.400	65.600	73.800	82	98.400
250	264.4	36.400	45.50	54.600	63.700	72.800	81.900	91	109.200
275	289.4	39.600	49.50	59.400	69.300	79.200	89.100	99	118.800
300	314.4	43.760	54.70	65.640	76.580	87.520	98.460	109	131.280
350	364.4	50.160	62.70	75.240	87.780	100.320	112.860	125	150.480
400	414.4	56.800	71.00	85.200	99.400	113.600	127.800	142	170.400
500	514.4	70.600	88.25	105.900	123.550	141.200	158.850	176	211.800

Table 95—HORIZONTAL ABSORBERS, CAPACITY IN THOUSANDS OF CUBIC FEET PER 24 HOURS, PER FOOT OF LENGTH

Pressure in Lb.		Diameter of Absorber							
Gauge	Absolute	30 in.	36 in.	42 in.	48 in.	60 in.	72 in.	84 in.	96 in.
0	14.4	7.41	8.892	10.374	11.856	14.82	17.784	20.748	23.712
25	39.4	20.28	24.336	28.392	32.448	40.56	48.672	56.784	64.896
50	64.4	33.06	39.672	46.284	52.896	66.12	79.344	92.568	105.792
75	89.4	45.90	55.080	64.260	73.440	91.80	110.160	128.520	146.880
100	114.4	58.56	70.272	81.984	93.696	117.12	140.544	163.968	187.392
125	139.4	71.70	86.040	100.380	114.720	143.40	172.080	200.760	229.440
150	164.4	84.60	101.520	118.440	135.360	169.20	203.040	236.880	270.720
175	189.4	97.50	117.000	136.500	156.000	195.00	234.000	273.000	312.000
200	214.4	110.40	132.480	154.560	176.640	220.80	264.960	309.120	353.280
225	239.4	123.00	147.600	172.200	196.800	246.00	295.200	344.400	393.600
250	264.4	136.50	163.800	191.100	218.400	273.00	327.600	382.200	436.800
275	289.4	148.50	178.200	207.900	237.600	297.00	356.400	415.800	475.200
300	314.4	164.10	196.920	229.740	262.560	328.20	393.840	459.480	525.120
350	364.4	188.10	225.720	263.340	300.960	376.20	451.440	526.680	601.920
400	414.4	213.00	255.600	298.200	340.800	426.00	511.200	596.400	681.600
500	514.4	264.75	317.700	370.650	423.600	529.50	635.400	741.300	847.200

No correction to these values for the gravity of the gas is required since in this type of absorber the gravity of the gas does not affect the capacity. The capacities given in the table are for an absorber one foot long. For any other absorber multiply the capacity shown in table by the length of the absorber in feet.

Table 96—VERTICAL ABSORBERS. NUMBER REQUIRED PER MILLION CUBIC FEET OF GAS

Diameter of Absorber	Pressure Pounds per Square Inch										
Inches	0	10	20	30	50	75	100	150	200	300	400
8	33.	19.	14.	11.	7.4	5.3	4.1	2.9	2.2	1.5	1.1
10	21.	13.	8.9	6.9	4.7	3.4	2.7	1.9	1.4	.97	.74
12	15.	8.7	6.2	4.8	3.3	2.4	1.9	1.3	.99	.68	.51
14	11.	6.4	4.5	3.5	2.4	1.7	1.4	.95	.73	.50	.38
16	8.3	4.8	3.5	2.8	1.9	1.3	1.0	.73	.55	.38	.28
18	6.5	3.9	2.7	2.2	1.5	1.1	0.82	.57	.44	.30	.23
20	5.3	3.3	2.2	1.7	1.2	.85	0.68	.48	.35	.24	.19
24	3.7	2.2	1.5	1.2	.83	.63	0.48	.33	.25	.17	.13
30	2.4	1.4	1.0	.77	.52	.38	0.30	.21	.16	.11	.07
36	1.6	1.0	0.68	.55	.38	.28	0.21	.14	.11	.07	.06
42	1.2	0.71	0.50	.39	.27	.19	0.16	.11	.08	.06	.04
48	0.92	0.55	0.38	.30	.21	.16	0.12	.08	.06	.04	.03
60	0.60	0.35	0.25	.19	.13	.09	0.07	.05	.04	.03	.02
72	0.40	0.25	0.17	.14	.09	.07	0.05	.04	.03	.02	
84	0.30	0.18	0.13	.10	.07	.05	0.04	.03	.02		
96	0.23	0.14	0.09	.08	.05	.04	0.03	.02			

Based on flow of 60 feet per minute through absorber.

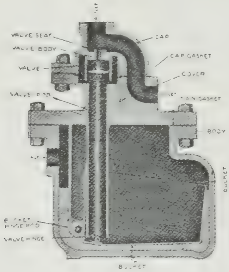


Fig. 105—STRONG GASOLINE TRAP

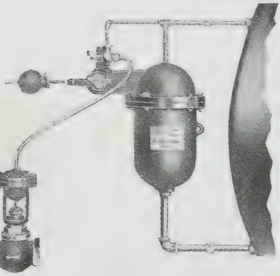


Fig. 106—CHAPLIN FULTON OIL LEVEL REGULATOR

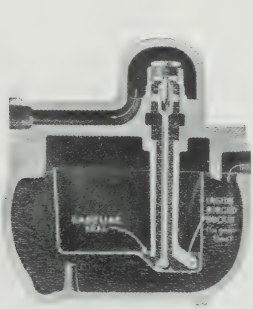


Fig. 107—SWARTOUT GASOLINE TRAP

Fig. 108—INTERIOR VIEW OF OIL TRAP HOUSE

Table 97
CAPACITY OF "STRONG" OIL TRAPS
Mineral Seal Oil

Size of trap.......	No. 2-0	No. 3-0	No. 4-0	No. 5-0	No. 6-0
Inlet pipe size....	1 in.	1¼ in.	1½ in.	2 in.	2½ in.
Outlet pipe size...	1 in.	1¼ in.	1½ in.	2 in.	2½ in.
Gals. per hour at 1 lb. pressure.....	140	300	720	940	1200
Do 50 Lb. do	1140	2120	4760	6440	8440
Do 80 Lb. do	1400	2680	6000	8160	10680
Do 110 Lb. do	1760	3140	7080	9640	12600
Do 150 Lb. do	2080	3760	8320	11600	15040
Do 300 Lb. do	2640	4710	10620	14460	18900

Vent Tank—This consists of a tank either horizontal or vertical into which the saturated oil is delivered by the traps. From this tank the saturated oil is pumped through the exchangers into the still. Its function is to provide a place where the oil traveling at a low velocity may separate from the more volatile constituents which it has absorbed in the absorber, some of which are permanently gaseous at ordinary temperatures and low pressures. These are released from the oil by the reduction of the pressure on the oil as it passes through the oil trap and are separated from the oil in the vent tank. Connections are shown by figure 109. The use of such a tank is not essential. The gases given off here may be carried through the exchangers to the still and will then come off with the tail gases from the condenser when they may be handled in the same manner as though they were taken off at the vent tank. The use of a vent tank, however, is very convenient in absorbing the pulsa-

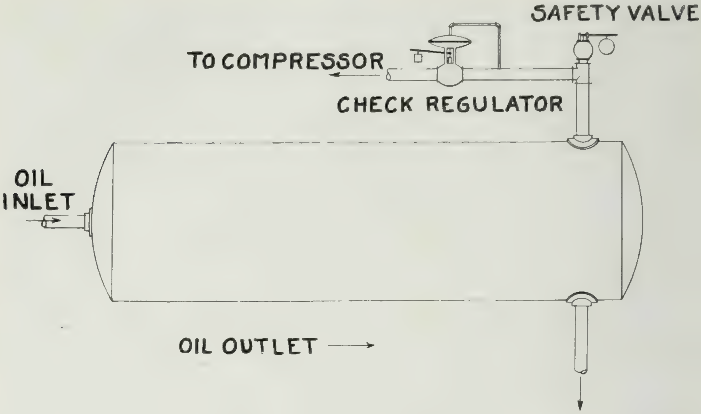


Fig. 109—VENT TANK

tions due to intermittent trap discharge, irregularities of high pressure pumps, etc., and is to be recommended. On low pressure plants, however, operating at pressure below 30 pounds, unless an excessive amount of absorbing oil is circulated, there is practically no release of gases by such a tank. This tank usually has a capacity up to the operating oil level of about two times the hourly rate of oil circulation. Where it is feasible to do so it simplifies the design and aids smoothness of operation to have this tank located at such an elevation that the oil will flow by gravity from the vent tank through the exchangers to the still. This eliminates the low pressure pumps.

Oil Pumps—The capacity of the oil pumps is dependent upon the rate of oil circulation. Table for this under different conditions of gasoline and content pressure are given on page 379, Table 92. For high pressure work outside packed plunger pumps are usually preferable though some manufacturers make an inside packed plunger type that is equally satisfactory. The packed piston type is suitable for low pressure work. Valves should be of brass. Pumps should be of over capacity to secure long life and reliability

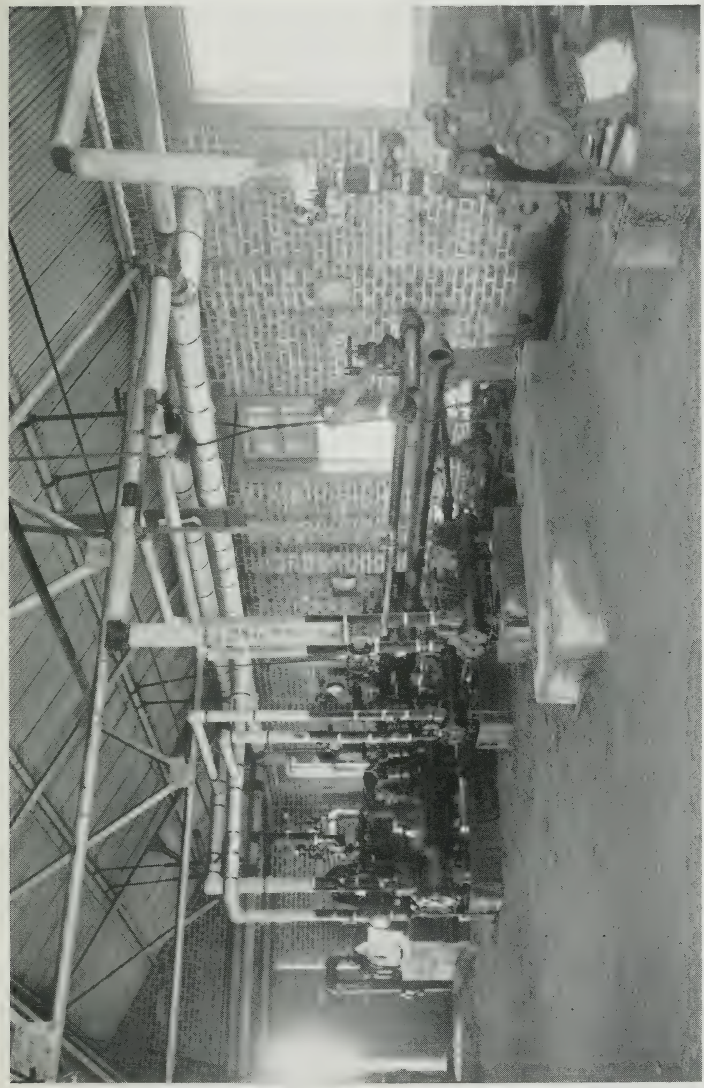


Fig. 110—OIL PUMPS AND COMPRESSOR

under continuous operation. It is advisable to have them in duplicate as a few shut-downs may soon pay for the extra pump.

Oil Cooler—There are several manufacturers of special apparatus for this work but the usual practice is to build an oil cooler of the atmospheric water cooled type from 2 in. pipe. Fig. 111 illustrates such a cooler. The oil should enter the bottom pipe and leave at the top, the water flowing down over the pipes. This condition is necessary for efficient use of the water and to secure the closest possible approach of oil temperatures to cold water temperature. Submerged oil coolers are undesirable on account of the formation of moss and scum and the difficulty of properly cleaning the cooling surface. The proportions of such a cooler should be such that the velocity of the oil is maintained at or above 120 feet per minute, this gives one 2 in. line a capacity of about 1000 gallons per hour so in a plant where the oil circulation is 6000 gallons per hour there would be required six 2 in. lines to carry the oil. The rate of heat exchange depends more upon the condition of the pipe surface than any other factor. For purposes of design it may be taken at 20 B. t. u.'s per sq. foot per degree mean difference between water and oil temperatures and the cooling effect of the atmosphere on the water may be neglected.

Then if the oil be cooled to within 5 degrees of the water temperature and the water is to be allowed to be heated to within 15 degrees of the hot oil temperature the mean temperature difference between water and oil is 9.12 degrees whatever the range of temperature. (Hausbrand, "Evaporating, Condensing and Cooling Apparatus"). This figure may be used in designing.

Table 98 shows the number of lineal feet of 2 in. pipe required per gallon of oil to cool it to 5 degrees above the water temperature with the water being heated to 15

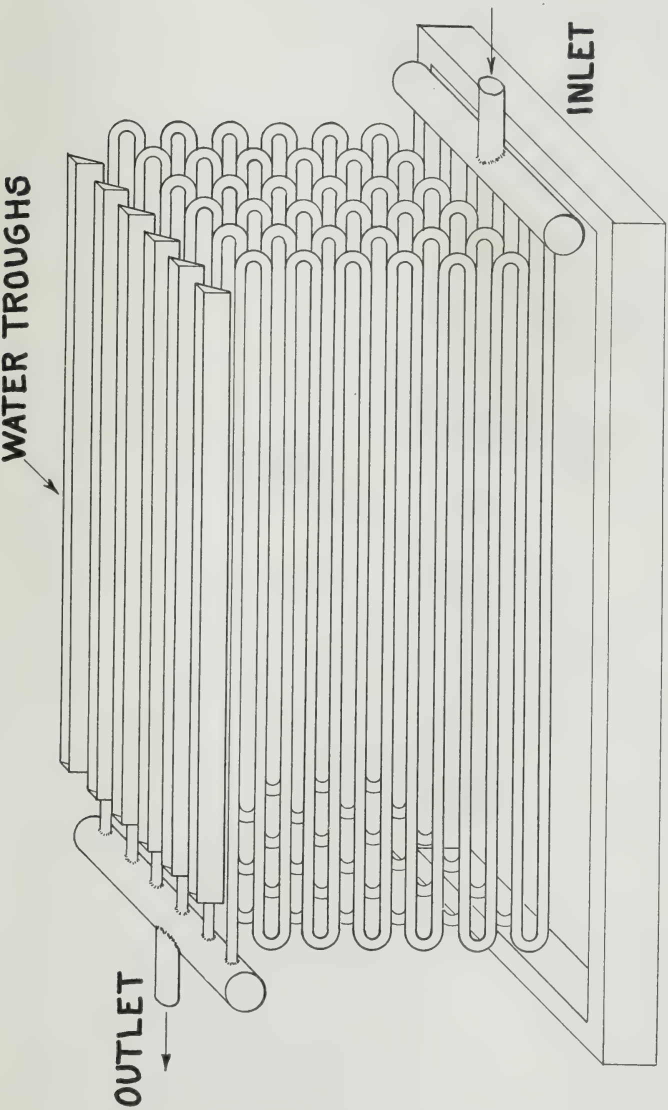


Fig. 111—OIL COOLER

degrees below the inlet oil temperature, based on a heat transfer rate of 20 B. t. u.'s per hour per square foot per degree mean temperature difference, a specific heat of the oil of .5 and a weight per gallon of the oil of 7 pounds.

Table 98

OIL COOLERS—MEAN TEMPERATURE DIFFERENCE 9.12 DEG. FAHR.

Rate of Heat Transfer, 20 B. t. u's per sq. ft. outside pipe surface per deg. per hour

Oil Inlet deg. fahr.	135	125	115	105	95	85	75	65	55	B. t. u.'s to be extracted per gal. of oil	Sq.ft. of surface required per gallon of oil per hour	Lineal feet of 2 in. pipe required per gallon of oil per hour
Oil Outlet temp. deg. fahr.	60	50	40	30	20	10				262.5	1.450	2.320
	70	60	50	40	30	20	10			227.5	1.250	2.010
	80	70	60	50	40	30	20	10		192.5	1.050	1.690
	90	80	70	60	50	40	30	20	10	157.5	.864	1.390
	100	90	80	70	60	50	40	30	20	122.5	.670	1.080
		100	90	80	70	60	50	40	30	87.5	.480	.773
			100	90	80	70	60	50	40	52.5	.290	.467
				100	90	80	70	60	50	17.5	.096	.155

If water be abundant so that it is not necessary to allow the water to heat up to within 15 degrees of the oil temperature as in the above table, the amount of cooling surface may be somewhat reduced. If the water is allowed to heat up to 20 degrees below the hot oil temperatures the mean temperature difference (for cooling the oil to 5 degrees above water temperature), becomes 10.83 degrees, and only 84

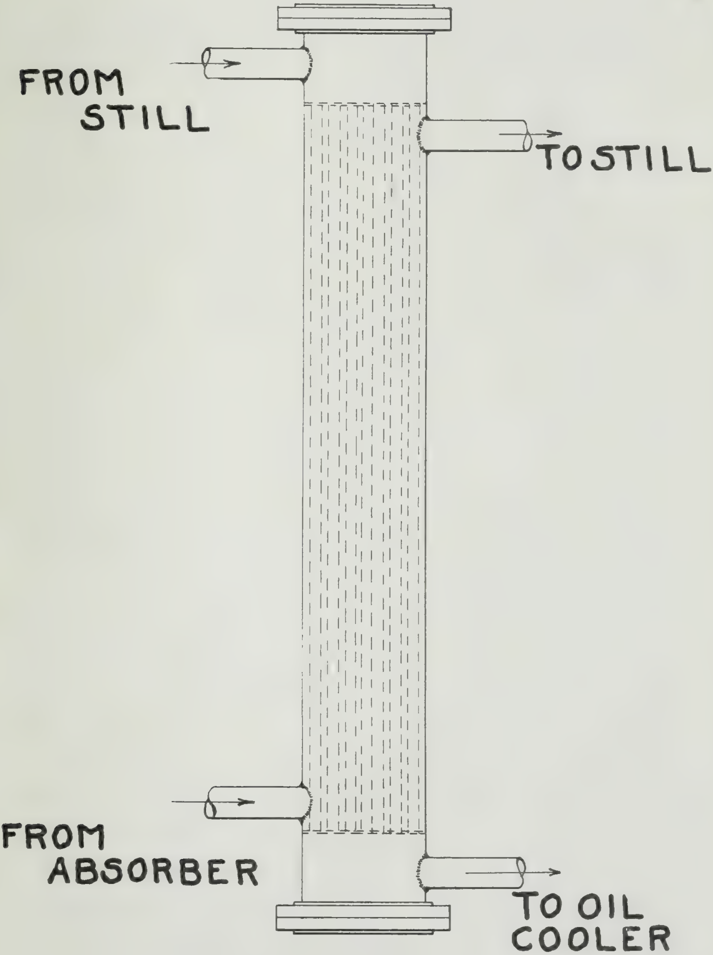


Fig. 112—VERTICAL HEAT EXCHANGER

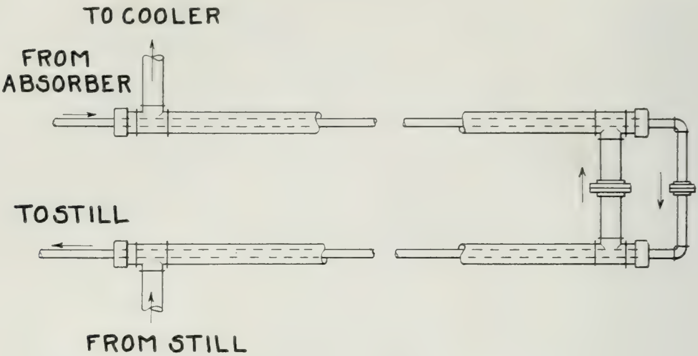


Fig. 113—HORIZONTAL HEAT EXCHANGER

per cent of the above cooling surface is required. If the water leaves the cooler at 25 degrees below inlet oil temperatures the mean temperature difference is 12.45 degrees and only 75 per cent of the cooling surface given in the table is required.

Example—A plant circulating 6000 gallons of oil per hour will have water of a temperature of 65 degrees. It is desired to cool the oil to 70 degrees (5 degrees above water temperature). The oil will enter the cooler from the exchanger at 105 deg.

In the 105 deg. column, Table 98, run down to 70 degrees (Outlet temperature of oil) then across to right hand column, 1.08 feet of 2 in. pipe is required per gallon or 6480 feet for 6000 gallons per hour.

This cooler should be 6 pipes wide (1000 gals. per pipe) and not less than 18 pipes high. This would make the cooler 50 feet long. An arrangement commonly used is shown in Figure 111.

Exchangers—These serve to transfer the heat from the hot oil leaving the still to the cold saturated oil passing to the still. They may consist of: Cylindrical shells with tubes through which the oil flows in one direction while the

Fig. 114—HEAT EXCHANGERS

oil flowing in the opposite direction surrounds the tubes; a double pipe arrangement when the oil flowing in one direction flows in the inner pipe while the oil flowing in the opposite direction flows between the two pipes; a system of concentric pipes, the oil flowing in opposite direction in the spaces between pipes.

These are illustrated by diagrams in Figs. 112 and 113.

Other types of special apparatus are offered by various manufacturers. The tubular exchanger should set with the tubes vertical or the oil will stratify in the exchangers and part of the exchanger surface will be inactive.

The rate of heat exchange depends somewhat upon the velocity of the oil and may vary from 20 to 50 B. t. u.'s per square foot per degree mean temperature difference.

For the vertical exchangers with 2 in. standard pipe tubes or their equivalent a rate of 20 B. t. u.'s per square foot per degree per hour may be safely used and a higher value used only where there is reliable data to support it.

Example:

Assume—The oil leaves the still at 210 deg. fahr.
The oil from the absorbers is at 60 deg. fahr.
The oil to be cooled in the exchangers to within 25 deg. fahr. of the temperature of the oil coming from the absorber or 85 deg. fahr.

Then if the heat loss by radiation in the exchangers is 10 per cent the rise in temperature of the cold oil will be about 90 per cent of the drop in temperature of the hot oil, or for this condition the cold oil will be heated to 172.5 deg. fahr.

The specific heat of absorbent oils which weighs about 7.0 pounds per gallon used is usually .50. The amount of heat to be extracted from each gallon of oil leaving the still is 3.5 B. t. u.'s per gallon for each degree that the oil is to be cooled in the exchangers. Then if the oil coming from the absorbers is at a temperature of 60 deg. fahr. and

the oil leaving the still is to be cooled to 85 deg. fahr. in the exchangers, a drop of 125 deg. fahr., there must be exchanged in the exchangers 3.5 x 125, or 437.5 B. t. u.'s per gallon of oil. If the rate of heat exchange per degree mean temperature difference per hour per square foot is 30 B. t. u.'s, and the mean temperature difference 30.8, then the rate of heat transfer per square foot is $30.8 \times 30 = 924$ B. t. u.'s per square foot and the exchanger surface required for each gallon of oil circulated per hour is $437.5 \div 924 = .473$ square feet of exchanger surface per gallon of oil circulated per hour.

In Table 99 are shown the amounts of heat to be extracted for various oil temperatures and the exchanger surface required per gallon of oil circulated per hour to obtain these temperatures.

It may be noted from Table 99 that the temperatures of the saturated oil going from the exchangers to the still varies but little (from 169.5 to 176.5) with the difference in temperatures of oil coming from the absorbers (30 deg. fahr. to 100 deg. fahr.), so that while the difference in temperature at the cold end of the exchangers has been taken as constant at 25 deg. fahr. the difference in temperature at the hot end varies only through a range of from 40.5 deg. (210—169.5=40.5) to 33.5 deg. (210—176.5=33.5). The mean temperature difference for these extreme conditions is 32.2 degrees and 29 degrees (See Hausbrand "Evaporating Condensing and Cooling Apparatus).

Where gas has little value and fuel consumption is not an important consideration a less efficient exchanger may be used, allowing the oil from the still to be cooled down to within only say 40 degrees of the temperature of the oil coming from the absorbers.

Table 100 gives the relative temperatures and exchanger surface for such conditions. The amount of exchanger surface is only about 60 per cent of that required

Table 99—EXCHANGER CAPACITY

Denuded Oil Cooled to 25 deg. fahr. above Saturated Oil Inlet. Allowances Made for 10 Per Cent Heat Loss in Exchangers

Denuded Oil			Saturated Oil				B. t. u.'s to be Exchanged per Gallon of Oil	Sq. Ft. Exchanger Surface Required per Gallon of Oil Circulated per Hour				
								B. t. u.'s per hour per sq. ft. per degree				
Still Outlet 210 deg. fahr.	Exchanger Outlet	Drop	From Absorbers	To Still	Rise 90 per cent of drop	Mean Temp. Diff.		20	30	40	50	60
	55	155	30	169.5	139.5	32.2	542.5	.840	.560	.420	.336	.280
	65	145	40	170.5	130.5	31.7	507.5	.800	.533	.400	.320	.267
	75	135	50	171.5	121.5	31.3	472.5	.790	.513	.385	.308	.257
	85	125	60	172.5	112.5	30.8	437.5	.710	.473	.355	.284	.237
	95	115	70	173.5	103.5	30.4	402.5	.662	.442	.331	.265	.221
	105	105	80	174.5	94.5	30.0	367.5	.612	.408	.306	.245	.204
	115	95	90	175.5	85.5	29.5	332.5	.562	.375	.281	.225	.188
	125	85	100	176.5	76.5	29.0	297.5	.504	.336	.252	.202	.168

Table 100—EXCHANGER CAPACITY

DENUDED OIL COOLED TO 40 DEG. FAHR. ABOVE SATURATED OIL INLET TEMPERATURES

ALLOWANCE MADE FOR 10 PER CENT HEAT LOSS IN EXCHANGERS

Denuded From Still			Saturated Oil				B. t. u.'s to be Exchanged per Gal. Oil	Sq. Ft. of Exchanger Surface Required per Gallon of Oil Circulated per Hour — B. t. u.'s per hour per sq. ft. per deg.				
Still Outlet deg. fahr.	Exchanger Outlet deg. fahr.	Drop	Inlet from Absorber deg. fahr.	Outlet to Still	Rise	Mean Temp. Diff.		20	30	40	50	60
210	70	140	30	156	126	46.6	490	.52	.35	.26	.21	.18
	80	130	40	157	117	46.2	455	.50	.33	.25	.20	.17
	90	120	50	158	108	45.7	420	.46	.31	.23	.18	.15
	100	110	60	159	99	45.3	385	.42	.28	.21	.17	.14
	110	100	70	160	90	44.8	350	.38	.26	.19	.16	.13
	120	90	80	161	81	44.3	315	.36	.24	.18	.14	.12
	130	80	90	162	72	43.8	280	.32	.22	.16	.13	.11
	140	70	100	163	63	43.4	245	.28	.19	.14	.12	.10

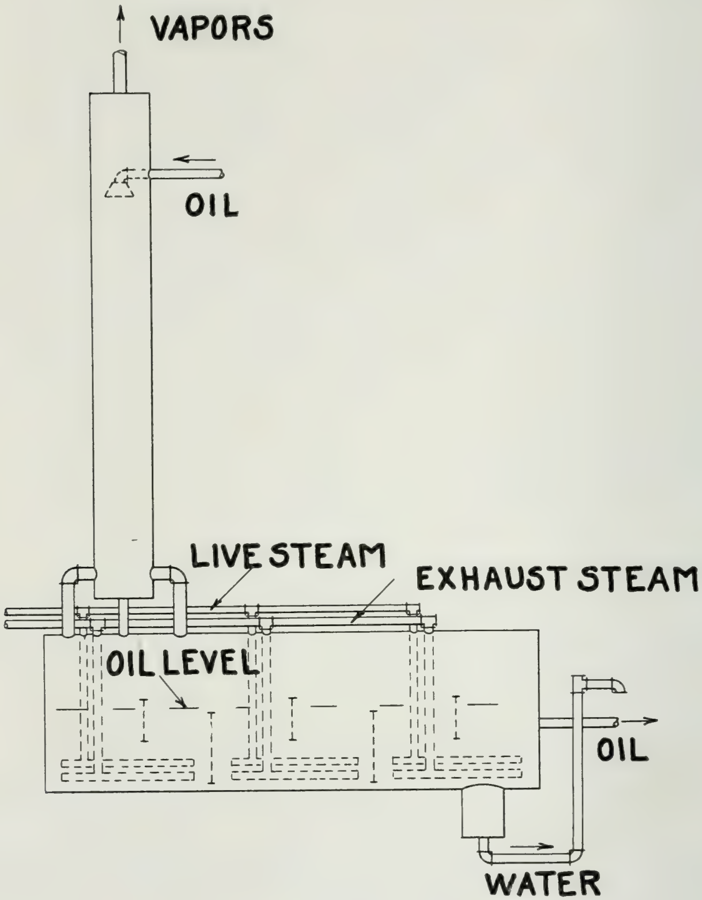


Fig. 115—STEAM STILL AND TOWER

to cool the oil from the still down to within 25 degrees of the saturated oil temperatures as in table 99.

The saving of exchanger installation here is made at the expense of the boiler installation and fuel consumption and additional cooling water supply.

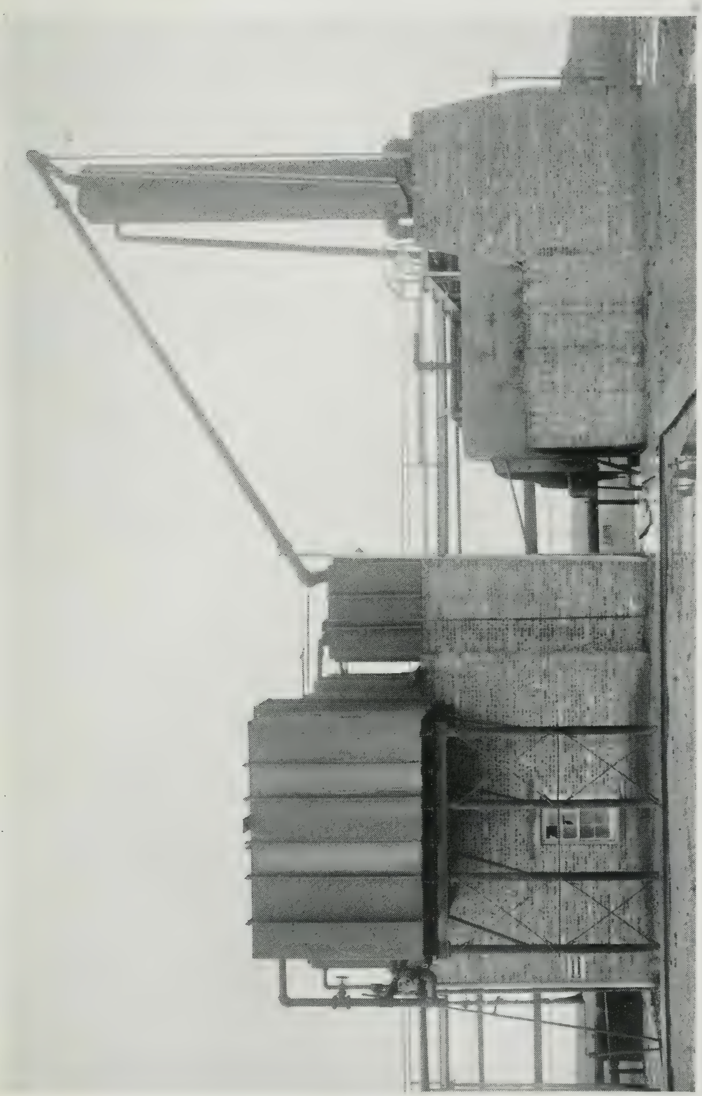


Fig. 116—STEAM STILL WITH CONDENSING COILS

Still—The type of still usually used is the steam still used in refinery work for running kerosene for the purpose of raising the flash point. It is illustrated by figure 115. Many variations can be made in the arrangement of baffles, arrangement of steam spray pipes, type of filling in towers, etc. The towers may be of the cap and bell washer type such as is used in alcohol and benzol distillation, but this is a refinement that is usually not warranted by the expense, the tower usually being filled with crushed hard limestone, 2½ in. to 5 in., hollow tile, sheet iron shearings or some such material that will provide large contact surface and large passage area.

The size of the still is dependent upon the amount of oil circulated. The length of the shell is usually not so great as in petroleum refining practice.

The capacity in gallons of oil per hour is about D x L x 40, where D is the diameter, and L the length, both in feet. Usual proportions are about as shown in the following table:

Table 101—STEAM STILLS

Still	Capacity in Gallons Oil per Hour	Size of Tower
4 ft. 00 in. x 15	2400 to 3000	20 in. x 20 ft.
5 ft. 00 in. x 20	4000 to 4333	24 in. x 20 ft.
6 ft. 00 in. x 20	4800 to 5400	30 in. x 25 ft.
8 ft. 00 in. x 25	8000 to 10666	42 in. x 25 ft.
10 ft. 00 in. x 30	12000 to 16000	50 in. x 30 ft.
12 ft. 00 in. x 35	16800 to 22400	60 in. x 30 ft.

The still may be bricked in as in usual refinery practice or merely set on steel or masonry piers or cradles and insulated all over with 1½ in. of good heat insulating material. The latter is the most economical and fills all requirements. The tower may be set upon a masonry or structural steel support and insulated in same manner as the still.

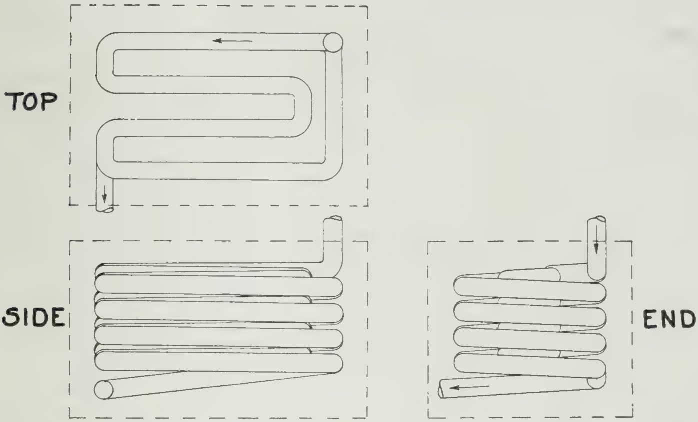


Fig. 117—CONDENSER WORM

The steam piping inside the still consists of 2 in. pipe perforated on the upper side with 1/8 in. to 3/16 in. diameter holes to admit the steam into the body of the oil. It is usually advisable to have two sets of steam spray pipes, one for high pressure steam and one for exhaust steam. The two may be externally connected, with check valves in the connections so that exhaust steam may enter the high pressure spray pipes but high pressure steam cannot enter the exhaust steam pipes. The water level in the still must be kept below the steam pipes at all times and the steam must spray upward to avoid emulsifying the oil. The lineal feet of two inch exhaust steam spray pipe should be about 3/4 x length of still x diameter of still, both dimensions being in feet. About half this amount of high pressure steam piping is required. The perforations can be made in three rows—the holes in each row being spaced about one inch apart.

The baffles are arranged so that the oil passes alternately over and under the baffles. For an eight foot still, one set should reach from center line of still to about 4 in. above

bottom of still. The other set should reach from about one foot above center line of still to about eighteen inches above bottom of still.

Condensers—The first condenser through which the vapors from the tower pass is used to condense the heavy oil carried over through the tower. This heavy oil is returned to the still through the run back line. It may be piped up as one continuous worm or may be piped up with two or more lines in parallel, but care must be taken to prevent any pockets.

The size of the vapor pipe from the tower to this condenser and the areas through the first or auxiliary condenser should not be less than the values found from the following equation which gives twice the area allowed by I. I. Redwood.

$$d^2 = \frac{\text{Gallons per day}}{188}$$

Where d = diameter of vapor pipe and G = gallons of gasoline per day. On this basis vapor pipes have the following capacities:

Table 102—VAPOR LINES

Vapor pipe size	Gal. of Gasoline per day
2 in	750
2½ in	1175
3 in	1692
4 in	3000
6 in	6770
8 in	12040
10 in	18800
12 in	27070

Thus an auxiliary condenser worm for a plant of 12,000 gallons per day capacity might be made a single 8 in. worm or two 6 in. worms, or four 4 in. worms.

The amount of condensing surface in this condenser should be half that of the main condensers.

The vapor and condensate from the first or auxiliary condenser should pass through a separating chamber to

separate the heavy oils and the water that have been condensed in the auxiliary condenser. A sketch of a satisfactory separating box and siphon column for this purpose are shown in figure 99.

The vapors from the separating box are led to the main condenser through pipes of the same area as the vapor pipe connecting the stone tower to the still. For about one-third the length of the worm this area should be maintained, the middle third should have about two-thirds this area and the last third about one-third of this area. (See I. I. Redwood, Mineral Oils and their By-Products).

The main condenser should have not less than 2 sq. ft. of condensing surface for each gallon of condensate per hour when the cooling water is to be allowed to rise to 90 degrees, and if the cooling water is allowed to rise to 125 degrees, 5 sq. ft. should be allowed for each gallon of condensate per hour with proportionate allowance for intermediate temperatures.

The main condenser may, if desired, be composed of several worms in parallel as in the auxiliary condenser.

To conserve water the auxiliary condenser may be cooled by the waste water from the main condenser. In both cases the cooling water supply should enter the bottom of the box and overflow at the top and provisions for drawing off the sediment that will accumulate should be made.

Temperature Control of Auxiliary Condenser—The temperature of the outlet of the auxiliary condenser should be controlled within close limits.

Too high a temperature at this point results in the carrying over into the main condenser of some of the absorbent oil. Too low a temperature results in the return to the still of gasoline which will not only result in increased steam consumption but will allow the denuded oil leaving the still to contain an appreciable percentage of gasoline which will impair its absorbing power.

Table 103—CONDENSER PIPING

The condenser capacity for various sizes of plants will then be about as follows:

Gallons of Gasoline per day	Vapor Pipe Size	Aux. Condenser		Main Condenser					
				Sq. ft. surface			Size Pipe		
				Outlet Water Temp.					
		Sq. ft. Surface	Size Pipe	90	110	125	First 1/3	Middle 1/3	Last 1/3
	inches		inches				inches	inches	inches
750	2	50	2	63	117	156	2	2	2
1175	2½	75	2½	98	183	245	2½	2	2
1690	3	107	1–3 or 2–2	141	262	352	3	2½	2
3000	4	188	1–4 or 4–2	250	466	625	4	3	2½
6770	6	423	1–6 or 2–4 or 4–3 or 9–2	555	1045	1410	6	4	3
12040	8	750	1–8 or 2–6 or 4–4 or 16–2	1000	1860	2510	8	6	4
18800	10	1175	1–10 or 3–6 or 6–4 or 11–3 or 25–2	1565	2910	3915	10	8	6
27070	12	1692	1–12 or 4–6 or 9–4 or 16–3 or 36–2	2260	4180	5650	12	10	8

The temperature at this point is readily controlled by a thermostatic valve, operated by temperature changes at the outlet of this condenser and controlling the rate of flow of the incoming cooling water. To make such a valve sensitive the volume of water contained in the tank should be as small as possible which requires that the tank be as small as practicable to contain the required cooling surface. A by-pass may be installed around the thermostatic valve and only a portion of the water going to the auxiliary condenser passed through this valve.

Oil Meters and Gas Meters—Proper operation and efficient extraction of gasoline can only be obtained when the proper amount of oil is circulated in proportion to the gas passed.

To maintain the proper ratio at all times it is necessary to measure the oil and gas. For this purpose any of the standard instruments are adaptable. Orifice outfits with recording gauges are particularly convenient for such work. The data on such outfits for purposes of design can be secured from the manufacturers of such apparatus.

Tail Gas Compressor—This machine recompresses the gases given off by the vent tank and the uncondensed vapors from the still.

If it is desired to secure the gasoline vapors from these gases by straight compression and cooling, the gases should be compressed to about 200 pounds or higher, but if these gases are to be treated again by absorption, either with mineral seal or naphtha they need only be compressed to the pressure at which the final residue gas may be disposed of.

In a high pressure installation it is usually desirable to return this residue into the transmission line so that the reduction in heating value of the gas may be kept at a minimum, these gases being of a very high heating value.

The required capacity of such a compressor is dependent upon the nature of the gas and the pressure at which it is treated. A rough approximation of the capacity required may be obtained from the following equation:

Capacity of Compressor cu. ft. per minute free gas = .06 × gal. of gasoline per day, total yield.

Water Requirements—Water is required for boiler feed, oil cooling, main condensers and gas cooler on tail gas compressor.

The condensation from the still makes an excellent feed water if properly settled and skimmed to separate the oil before going to the boiler. The deficiency of this supply may be made up from the overflow from the auxiliary condenser. Hot water for boiler feed being thus available no feed water heater is needed in the boiler room.

The water for the auxiliary condenser may be taken from the overflow from main condensers. A supply must be provided then for oil cooler, main condenser and gas cooler on tail gas compressor.

The water requirements for the main condenser are dependent upon the amount of gasoline to be produced. Taking the latent heat of gasoline at 100 B. t. u.'s and its specific heat at about .58 and its weight at 5.5 pounds per gallon and figuring on cooling it to approximately the temperature of the inlet cooling water supply the amount of water required for this purpose per gallon of gasoline is shown in Table 104 which was computed as per the following example.

Example:

The temperatures of the vapors entering the main condenser will for most installations be not under 180 deg. fahr. or over 190 deg. fahr. For water calculations assume the higher figure.

Assume a water temperature of 65 deg. fahr. at the inlet to condenser and allow the water to rise in temperature to

120 degrees. Then each pound of water will absorb 120—65=55 B. t. u.'s per pound, or 458 B. t. u.'s per gallon.

Each gallon of gasoline will release $(100\times5.5)+(190-65)\times.58\times5.5=948.75$ B. t. u.'s per gallon. This will then require $\frac{948.75}{458}=2.07$ gal. of water per gallon of gasoline.

If the condensing water be allowed to rise in temperature only to 90 degrees then each gallon of water will absorb $(90-65)\times8.33=208.25$ B. t. u.'s, and the cooling water required will be $\frac{948.75}{208.25}=4.55$ gal. of water per gallon of gasoline.

Table 104

CONDENSING WATER MAIN CONDENSER

Cooling Water Temperatures		Gallons of Water required per gallon of gasoline condensed
Inlet	Outlet	
50	90	3.72
	100	2.97
	110	2.47
60	90	4.82
	100	3.61
	110	2.89
70	90	7.02
	100	4.66
	110	3.50
80	100	6.76
	110	4.50
	115	3.86
90	105	8.70
	115	5.20
100	115	8.70
	125	5.20

Table 105

WATER REQUIRED FOR OIL COOLER

Temperature of Cooling Water		Temperature of Oil		Gallons of Water per Gallon of Oil circulated
Inlet	Outlet	Inlet	Outlet	
55	65 80	85 100	60	1.310 .844
65	75 90	95 110	70	1.310 .844
75	85 100	105 120	80	1.310 .844
85	95 110	115 130	90	1.310 .844
95	105 120	125 140	100	1.310 .844

To care for the condensation of steam in the main condenser and allow a safe margin in the supply, these figures are increased by 25 per cent in the table.

The amount of water required for the oil cooler is shown in Table 105. The following example shows the method of calculating these quantities.

Example:

Assume the exchanger has cooled the oil from the still to a temperature of 100 degrees, that the temperature of the cooling water available is 55 degrees fahr. and that the oil is to be cooled to within 5 degrees the cooling water, or 60 degrees, and that the cooling water is to be allowed to rise in temperature to within 20 degrees of the oil temperature, or 80 degrees. The specific heat of the oil is about .50 and its weight about 7 pounds per gallon. The heat to be extracted per gallon is then 3.5 B. t. u.'s per degree of cooling or 140 B. t. u.'s per gallon for cooling 100 deg. fahr. to 60 deg. fahr. The water in being raised from 55 deg. fahr.

to 80 deg. fahr. will absorb $8.33\times(80\text{-}55)=208.25$ B. t. u.'s per gallon. Then neglecting the effect of heat absorption due to water evaporation by the atmosphere, for each gallon of oil circulated there will be required $\frac{140}{208.25}$ equal to .675 gallons of water to cool the same. An additional 25 per cent is allowed in Table 105.

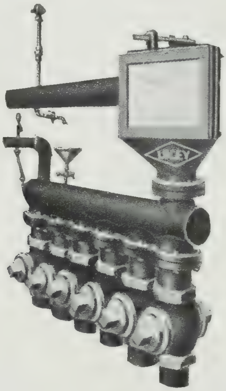


Fig. 118—RECEIVING HEAD

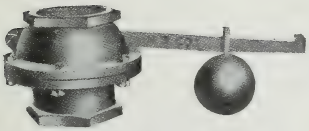


Fig. 119—VACUUM VALVE FOR OIL STILLS

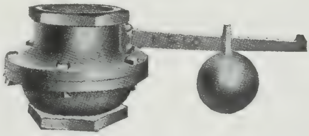


Fig. 120—SAFETY VALVE FOR OIL STILLS

Boiler Capacity—The steam requirements for an absorption plant are dependent upon the gasoline production, the rate of oil circulation and the temperature of the oil entering the still. Heat enough must be supplied to the oil to raise it from the temperature at which it enters the still to the temperature at which it leaves the still and this

heat is derived from the condensation of steam in the still. An additional amount of steam must pass through the tower to the auxiliary condenser to carry over the gasoline.

Assume that the saturated oil leaving the exchangers and entering the stone tower is at a temperature of 160 deg. fahr. It is to be heated in the still to the temperature at which the steam condenses, about 215 deg. fahr., (about one pound pressure in the still) a rise of 55 degrees requiring 55 x .50x7 = 192.5 B. t. u.'s per gallon of oil. The steam used is almost entirely exhaust steam from pumps and compressors about the plant and will enter the still at about 3 pounds pressure, saturated, corresponding to a temperature of about 219.4 deg. fahr. and a heat content above 32 deg. fahr. of 1153.1 B. t. u.'s per pound. It leaves the still as water at about 210 deg. fahr. with a heat content above 32 deg. fahr. of 178 B. t. u.'s per pound, a difference of 975 B. t. u.'s per pound. Thus there is required for the condition $\frac{192.5}{975} = .197$ pounds of steam per gallon of oil to raise the temperature of the oil. Actual measurement of the water condensed in an 8 in. x 25 in. still under these temperature conditions with 4000 gallons of oil per hour circulation, the oil containing 1.72 per cent of gasoline showed 950 pounds of water condensed per hour or .2175 pounds per gallon of oil which at 55 degrees temperature rise is .00395 pounds of steam per gallon of oil per degree of temperature rise. At the same time the condensation from the auxiliary condenser was 1860 pounds of water per hour, this being the amount of free steam passing up through the stone tower to carry over the gasoline. The gasoline production was 68.7 gallons per hour so the steam condensed in the auxiliary condensers was 27.1 pounds of steam per gallon of gasoline and .465 pounds of steam per gallon of oil and .27 pounds of steam per gallon for each per cent of saturation.

The steam consumption may then be expressed by an equation as follows:

Pounds of steam per hour = gallons of oil in circulation per hour x [(Temperature rise of oil x .00395) + (per cent saturation x .27)].

This steam is usually generated at high pressure for operating pumps, etc. If this steam be generated at 125 pounds gauge from feed water at 200 degrees, each pound of water evaporated is equivalent to 1.0555 pounds evaporated from and at 212 deg. fahr. and since 34½ pounds evaporated from and at 212 deg. fahr. is one boiler horse power each pound of steam requires 1.0555 ÷ 34.5 = .030595 boiler horse power; and the boiler horse power required for this feed water temperature is .030595 x gal. of oil circulated per hour x [(Temperature rise of oil x .00395) + (per cent saturation x .27)] or boiler hp. = gallons of oil circulated per hour x [(Temperature rise of oil x .000121) + (per cent. saturation x .00826)].

The boiler horse power required for various conditions of feed water temperatures and for various temperatures of oil inlet to still and saturation per centages is shown in Tables 106 to 110.

Fig. 121

Table 106—BOILER HORSE POWER REQUIRED FOR ABSORPTION PLANTS PER GALLON OF ABSORBENT OIL CIRCULATED PER HOUR

Oil Inlet to Still, 180 deg. Fahr. (35 deg. Rise)

Percent Saturation of Absorbent Oil	Feed Water Temperatures, degrees fahr.			
	80	120	160	200
0.5	.00934	.00901	.00869	.00836
1.0	.01395	.01346	.01298	.01249
1.5	.01857	.01792	.01727	.01662
2.0	.02318	.02237	.02156	.02075
2.5	.02780	.02682	.02586	.02488
3.0	.03241	.03127	.03015	.02901
3.5	.03702	.03572	.03444	.03314
4.0	.04164	.04018	.03873	.03727
4.5	.04625	.04463	.04302	.04140
5.0	.05087	.04908	.04732	.04552
5.5	.05548	.05353	.05161	.04966
6.0	.06009	.05798	.05590	.05379
6.5	.06471	.06244	.06019	.05792
7.0	.06932	.06689	.06448	.06205

Table 107—BOILER HORSE POWER REQUIRED FOR ABSORPTION PLANTS PER GALLON OF ABSORBENT OIL CIRCULATED PER HOUR

Oil Inlet to Still, 170 deg. fahr. (45 deg. Rise)

Percent Saturation of Absorbent Oil	Feed Water Temperatures, degrees fahr.			
	80	120	160	200
0.5	.01069	.01030	.00995	.00957
1.0	.01530	.01477	.01424	.01370
1.5	.01992	.01922	.01853	.01783
2.0	.02453	.02367	.02282	.02196
2.5	.02915	.02812	.02712	.02609
3.0	.03376	.03258	.03141	.03022
3.5	.03837	.03703	.03570	.03435
4.0	.04299	.04148	.04000	.03848
4.5	.04760	.04593	.04229	.04261
5.0	.05222	.05038	.04849	.04674
5.5	.05683	.05484	.05279	.05087
6.0	.06144	.05929	.05708	.05500
6.5	.06606	.06474	.06137	.05913
7.0	.07067	.06819	.06566	.06326

Table 108—BOILER HORSE POWER REQUIRED FOR ABSORPTION PLANTS PER GALLON OF ABSORBENT OIL CIRCULATED PER HOUR

Oil Inlet to Still, 160 deg. fahr. (55 deg. Rise)

Percent Saturation of Absorbent Oil	Feed Water Temperatures, degrees fahr.			
	80	120	160	200
0.5	.01204	.01162	.01120	.01078
1.0	.01665	.01607	.01549	.01491
1.5	.02127	.02052	.01979	.01904
2.0	.02588	.02497	.02408	.02317
2.5	.03050	.02943	.02837	.02730
3.0	.03511	.03388	.03267	.03143
3.5	.03972	.03833	.03696	.03556
4.0	.04434	.04278	.04125	.03969
4.5	.04895	.04723	.04554	.04382
5.0	.05357	.05169	.04984	.04795
5.5	.05818	.05514	.05413	.05208
6.0	.06279	.06059	.05842	.05621
6.5	.06741	.06504	.06272	.06034
7.0	.07202	.06949	.06701	.06447

Table 109—BOILER HORSE POWER REQUIRED FOR ABSORPTION PLANTS PER GALLON OF ABSORBENT OIL CIRCULATED PER HOUR

Oil Inlet to Still, 150 deg. fahr. (65 deg. Rise)

Percent Saturation of Absorbent Oil	Feed Water Temperatures, degrees fahr.			
	80	120	160	200
0.5	.01339	.01292	.01246	.01199
1.0	.01800	.01737	.01675	.01612
1.5	.02262	.02182	.02104	.02025
2.0	.02723	.02628	.02534	.02438
2.5	.03185	.03073	.02963	.02851
3.0	.03646	.03518	.03392	.03264
3.5	.04107	.03963	.03821	.03677
4.0	.04569	.04408	.04251	.04090
4.5	.05030	.04854	.04680	.04503
5.0	.05492	.05299	.05109	.04916
5.5	.05953	.05744	.05539	.05329
6.0	.06414	.06189	.05968	.05742
6.5	.06876	.06634	.06392	.06155
7.0	.07337	.07080	.06827	.06569

Table 110—BOILER HORSE POWER REQUIRED FOR ABSORPTION PLANTS PER GALLON OF ABSORBENT OIL CIRCULATED PER HOUR

Oil Inlet to Still, 140 deg. Fahr. (75 deg. Rise)

Per cent Saturation of Absorbent Oil	Feed Water Temperatures, degrees fahr.			
	80	120	160	200
0.5	.01473	.01422	.01371	.01319
1.0	.01935	.01868	.01801	.01732
1.5	.02397	.02313	.02230	.02145
2.0	.02858	.02758	.02659	.02558
2.5	.03319	.03203	.03088	.02971
3.0	.03781	.03648	.03518	.03384
3.5	.04242	.04094	.03947	.03797
4.0	.04704	.04539	.04376	.04210
4.5	.05165	.04984	.04806	.04623
5.0	.05626	.05429	.05235	.05036
5.5	.06088	.05874	.05664	.05449
6.0	.06549	.06320	.06094	.05862
6.5	.07011	.06765	.06523	.06275
7.0	.07472	.07210	.06952	.06688

SPECIFICATIONS FOR ABSORBENT OILS TO BE USED IN EXTRACTING GASOLINE FROM NATURAL GAS

The following shows specifications for three absorbent oils used in extracting gasoline from natural gas. They are typical of the "mineral seal oil" now used almost entirely throughout the country in gasoline absorption work.

Oil No. 1	Oil No. 2	Oil No. 3
Absorbent Oil		
Gravity=40.7 deg. B.	35.6	36.9
I. B. P.=500 deg. fahr.	536	523
F. B. P.=666 deg. fahr.	698	680
Fire Test=312.8 deg. fahr.	312.8	318
Saybolt Visc.=45/100 deg. fahr.	49.5/100	48.5/100

Usually no specification is made as to color on absorption oils.

The following is a representative distillation of "mineral seal oil" used in absorbing gasoline from natural gas.

Over	273 deg. cent.
5 per cent	295 " "
10 "	300 " "
15 "	302 " "
20 "	305 " "
25 "	306 " "
30 "	308.5 " "
35 "	308.5 " "
40 "	311 " "
45 "	312.5 " "
50 "	316 " "
55 "	319.5 " "
60 "	322 " "
65 "	325 " "
70 "	329 " "
75 "	331 " "
80 "	336.5 " "
85 "	347 " "
91 "	360 " "
Residue	8.2 per cent.
Loss	.75 per cent.

A "cold test" determination, using the Franklin method of the Atlantic Refining Company, showed 30 deg. fahr. Using the Pennsylvania Railroad method the cold test was 17 deg. fahr.

Distillation Absorption Gasoline—With Natural Gas Gasoline the authors advise that in bringing the initial charge up to the boiling point, about 5 minutes be taken and the total time of distillation be about 45 minutes to avoid high distillation losses with these volatile grades.

The following curves, Figures 122 and 123, run as noted show representative distillations of still product and high-test gasoline or compression product obtained from a "dry" Natural Gas yielding 150 gallons per million feet.

Fig. 122

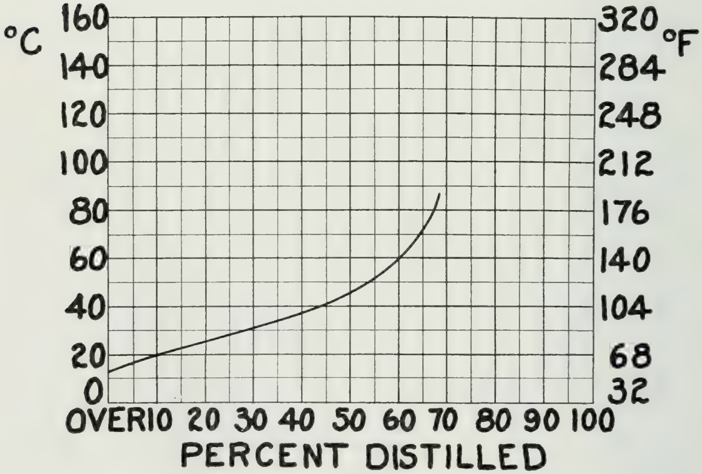


Fig. 123

ABSORPTION GASOLINE

Distillation of Still Gasoline Obtained by Condensers from Steam Still. See Fig. 122.

Baume Gravity—80.0 at 60 deg. fahr.
Specific Gravity—0.6667 at 60 deg. fahr.
Color—Water White.
Odor—O. K.
Acid—None.
Unsaturated Hydrocarbons—Less than 7 per cent.

Distillation 100 cc.—Engler Standard

Over	74.8	deg. fahr.
10 per cent	97.5	" "
20 "	114.3	"
30	127.6	' "
40 "	141.0	" "
50 "	155.1	" "
60 "	171.1	" "
70 "	189.5	" "
80 "	218.1	" "
90 "	276.6	" "
92 "	302.0	" "
Residue	1.4	per cent.
Loss	6.6	per cent.

ABSORPTION GASOLINE

Distillation of High Test Gasoline

Obtained by compression of tail gases and vent tank gases in absorption plant. See Fig. 123.

Baume Gravity—99 deg. at 60 deg. fahr.
Specific Gravity—0.6114 at 60 deg. fahr.
Color—Water White.
Odor—O. K.
Acid—None.
Unsaturated Hydrocarbons—Less than 7 per cent.

Distillation 100 cc.—Engler Standard

Over	54	deg. fahr.
10 per cent	68	" "
20 "	78	" "
30 "	87	" "
40 "	98	" "
50 "	112	" "
60 "	134	" "
65 "	160	" "
68 " dry	190	" "
Residue	0.8	per cent.
Loss	31.2	"

Saturation of Absorbent Oil, To and From Absorbers—In order to determine the efficiency of the plant under ordinary operating conditions, the following tests should be made frequently by the works chemist.

Test to Determine Saturation of the Absorbent Oil to and from the Absorbers.

800 cc. of the oil to be tested, either enriched oil from the absorbers or denuded oil from the stills is placed in distillation flask set up as shown. See Fig. 124.

Flask 1000 cc.—Copper.

Exit tube 10 in. long, ¾ in. iron tubing.

Thermometer bulb 2½ in. below outlet of exit tube.

3-bulb condensing tube, capacity about 90 cc. (entire tube and bulb).

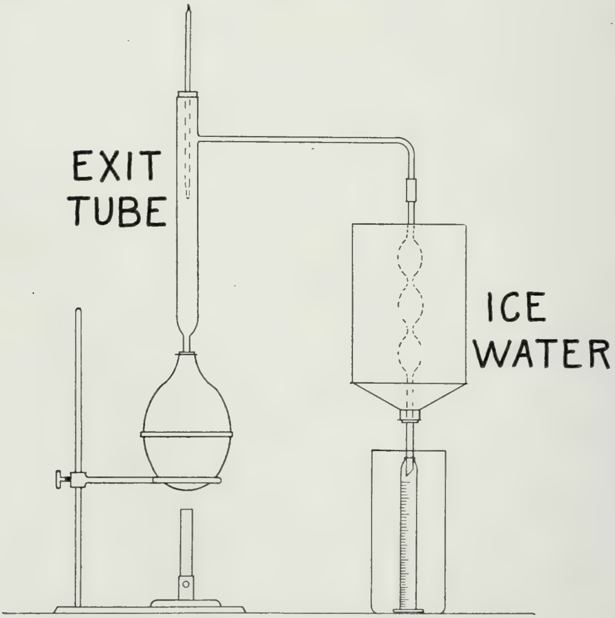


Fig. 124—DISTILLATION FLASK WITH ICE WATER CONDENSER

Condenser jacket made from 1 gallon tin can from which bottom was removed.

Condensate received in 10 cc. cylinder placed in beaker containing ice water mixture.

10 cc. cylinder graduated in tenths—reading error .01 cc. to .02 cc.

10 cc. cylinder calibrated with mercury by weighing.

Corks in flask and exit tubes coated with paste of litharge and glycerine.

Distillation stopped at 350 deg. fahr.

Top of receiving cylinder surrounded with cloth moistened with water.

The oil is heated until the thermometer reaches 350 deg. fahr. when distillation is stopped. From the number of cc. of distillate and the sample used, the saturation per cent is determined. For instance, if 800 cc. of enriched oil gave a distillate of 4 cc., the saturation per cent becomes

$$\frac{4}{800} \times 100 = 0.5 \text{ per cent.}$$

From the results of the two tests, the following is shown; First, whether the saturation of the enriched oil is so high that some gasoline is not extracted from the gas. Second, if the denuded oil from the stills shows any appreciable volume of distillate to 350 deg. fahr. it is evidence that the stills are not doing their work efficiently.

The difference between the two tests gives the increase in saturation due to gasoline absorption and the yield computed from this increase of saturation should check closely with actual plant production.

The following test on enriched oil from the absorbers, and data on actual gasoline production are of interest.

Oil from absorbers,	3.3 per cent saturation.
Oil to absorbers,	0.4 per cent "
	2.9 per cent available saturation.

At the time of test, 8500 gal. of oil per hour were being circulated. $0.029 \times 8500 = 246$ gal. gasoline per hour.

Actual yield of gasoline by tank gauge was 240 gallons for the hour.

This test is not to be taken as typical of efficient plant operation. At the time this test was made, the stills were not removing the gasoline completely. The oil to the absorbers should show only a trace of distillate to 350 deg. fahr. instead of that actually shown, 0.4 per cent.

Tests on Inlet and Outlet Gas—Frequent tests should be made with the portable single coil absorber on both inlet and outlet gas. The outlet gas from an efficient absorption plant should not show an appreciable content of salable gasoline, though it may show a considerable content of very volatile and unsalable liquid. If the content of salable liquid is high, investigate the relative temperatures, oil rates and pressures to increase the efficiency of extraction.

Test of Absorbent Oil for Emulsification—Improper control of the steam still may allow water to become emulsified with the oil. This not only gives the oil itself a lower absorbing power but misleads the operator as to the amount of oil he is circulating. The water content can be determined by a small hand power centrifuge and the water content of the oil kept down by proper regulation of water level in the still and proper setting of steam spray pipes.

Vapor Tension—The reader is referred to the instructions of the Bureau of Explosives, 30 Vesey Street, New York City, N. Y., for the regulations governing shipments of gasolines and instructions for taking vapor tension tests. A brief summary of these regulations and instructions will be found in part 14.

EFFECT OF GASOLINE EXTRACTION ON THE HEATING VALUE OF A GAS

The following formula expresses very closely the loss in heating value of a gas due to the extraction of a given volume of gasoline:

Let G = Gallons of gasoline extracted per million feet of gas.

H_1 = Heating value of gas before treating.

H_2 = Heating value of gas after a given volume of gasoline has been extracted.

$$H_2 = \frac{H_1 - \left(\dfrac{G \times 21{,}650 \times 5.42}{1{,}000{,}000}\right)}{1 - \left(\dfrac{G \times 35}{1{,}000{,}000}\right)}$$

and

Loss in heating value $= H_1 - H_2$

$$= H_1 - \frac{H_1 - \left(\dfrac{G \times 21{,}650 \times 5.42}{1{,}000{,}000}\right)}{1 - \left(\dfrac{35 \times G}{1{,}000{,}000}\right)}$$

The formula is based on a B. t. u. per pound of 85 degree gasoline of 21,650, a weight per gallon of 85 degree Baume gasoline of 5.42 pounds and the fact that 1 gallon of 85 degree gasoline if vaporized, would have a volume of about 35 cubic feet. No actual determination of the calorific value of this gasoline has been made by the authors. The figure is based on a formula* found to express the relation between gravity and calorific power (in British thermal units per pound) of American petroleum oils.

B. t. u. = 18,650 + 40 (Baume degrees — 10).

It is interesting to note how this formula holds against very careful calorimetric determinations. On one plant

* Sherman and Kropff—J. Am. Chem. Soc. 30 (1908), 1626.

where 150 gallons of gasoline per million feet of gas was extracted, heating value determinations were made on the inlet and outlet gas of the absorbers, with a very accurate calorimeter and meter. Tests were run for two weeks under different conditions. Gas samples were collected from inlet and outlet gas at the same time and analyzed on the Burrell modification of the Orsat gas machine. Results of determinations compared with the formula above are as follows:

Original Heating Value 1065 B. t. u. per cu. ft.

Loss in heating value as determined by analysis, 12 B. t. u.

Loss in heating value as determined by calorimeter, 11 B. t. u.

Loss in heating value as calculated from formula, 12 B. t. u.

EFFECTS OF EXTRACTING GASOLINE FROM "LEAN" NATURAL GAS BY THE ABSORPTION PROCESS ON THE DOMESTIC CONSUMPTION OF GAS

An antipathy has always existed in the minds of some gas consumers toward those who were furnishing the gas supply, and especially is this antipathy exaggerated during a gas shortage, these consumers feeling that something had been done or left undone deliberately on the part of the gas company to create the shortage. This feeling exists from lack of knowledge of the gas business and is a result of hasty judgment.

Since it has become generally known that certain kinds of natural gas carry gasoline vapor, and that certain processes have been utilized to condense this vapor and extract the gasoline from the gas, another imaginary cause for complaint has arisen and now added to the old complaints we find consumers accusing the gas company of robbing them by reducing the quality of the gas or making the shortage more

acute by decreasing the volume in extracting gasoline from the gas in the field. If it were possible to extract any great quantity of gasoline per thousand cubic feet from lean natural gas, some appreciable diminution in volume and heat units might result. We hear all kinds of assertions from thoughtless consumers where the impression seems to exist that lean natural gas will yield four or even more gallons of gasoline per thousand cubic feet, which is a statement that has no foundation in fact and cannot be corroborated. We are all too prone to make our accusation ahead of our investigation, and when the gas shortage is passed and city authorities and public service commissions have had time to investigate, it is found that the stories are largely exaggerated and filled with untruths.

Anything the newspapers can print on the subject of a corporation robbing the public appears in large type on the front page, while the final results of a fair investigating committee is seldom given space in any part of the paper, even in fine print. This is not always because the newspapers are anxious to print news of this character, but because the citizens seem more anxious to read it.

Primarily it should be said that gasoline has been taken from the gas for years and long before any regular process of extraction was perfected and used. Prior to the adoption of the absorption process the gasoline was collected in drips along the pipe line and, due to the low price of gasoline, was generally blown into the air or on the ground and wasted.

This was, of course, before the automobile came into general use and so materially increased the demand for gasoline. If a gas company had had the equipment for extracting gasoline and the market for disposing of it at this period, they would have greatly added to their income by the sale of this "drip" gasoline for that was the name it went by at that time.

All natural gas did not carry gasoline then nor does it today. Most gas wells do. It is true that as gas wells get older the quantity of gasoline in lean natural gas increases. Yet seldom will one find "lean" natural gas carrying over two or three pints per 1000 cu. ft. of gas.

Neither the absorption process nor the compression method will take all the gasoline vapors from lean natural gas or casinghead gas. The producing of several gallons of gasoline from 1000 cu. ft. of casinghead gas received a great deal of newspaper publicity, partially as it was a new business and partially on account of it being a conservation of our natural resources. Gas consumers have confused this process with the absorption process as applied to lean natural gas.

There is a vast difference between casinghead gas from an oil well, the pressure of which seldom exceeds 20 lb., which is rich in gasoline and the natural gas, which often will show a rock pressure of 900 lb. and carry from 1-10 of a pint to possibly two pints of gasoline per 1000 cu. ft. of gas. Casinghead gas has been known to carry as high as 13 gallons per 1000 cu. ft. of gas.

This gas is composed of gasoline vapors and natural gas and comes from an oil well at a low pressure. If it could be compressed to a high pressure sufficient to cause it to flow any distance in a pipe line that gasoline vapor would condense on the inside of the pipe line wherever it came in contact with a cold section of pipe, it would not require many miles of line to cause a large percentage of the gasoline vapors to condense and form free gasoline which would collect in the low places in the pipe line or in the drips.

What is true of casinghead gas is likewise true of "lean" natural gas only to a lesser degree due to the natural pressure of natural gas and the fact that it usually carries but a small amount of gasoline.

Natural gas is seldom found in the suburbs of the city using it and must be piped miles from the field to the domestic consumer. It necessarily follows the most direct line from the field to the city, over hills, through rivers and creeks and often exposed to the atmosphere in crossing gulleys. All of the foregoing creates ideal conditions to cool the gas, especially in winter, and condense the gasoline vapor from it.

If the gas field were located many miles from the point of consumption, and the gas were not treated by the absorption process, the consumer might receive approximately one per cent more gas than though that process was applied. The pipe line company would experience many troubles with regulators, meters and field lines filling with gasoline at the low points, unless dripped, for if untreated, natural gas carrying any gasoline at all, will condense wherever the gas comes in contact with a cold spot in the pipe line, just like the condensation of moisture in the air gathers upon the outside of a glass of ice water.

The actual effect on the domestic consumer in either lessening the quantity or in reducing the quality of the gas used by extracting gasoline from lean natural gas in the field is very small. The loss in volume when the field is located many miles from the city is less than 1 per cent in quantity and quality.

Loss of Heat Units in Gas due to removal of Gasoline*—The popular belief in the more than 2,100 towns and cities of the country where natural gas is used that the gas is being robbed of some of its heat value by the gas companies at the time when most needed through taking the gasoline from the gas, has been rudely upset by the Bureau of Mines, Department of the Interior, in a series of investigations just completed, which show that the more than 2,000,000 natural gas consumers lose practically no heating value through

*From the United States Bureau of Mines.

the process. In fact, taking all of the factors involved in this problem that have proved so troublesome and so misleading, and the Bureau of Mines claims that the taking of the gasoline from the natural gas is a benefit to the consumers and to the whole country, rather than a detriment.

It seems that whenever the weather becomes severe in a place where natural gas is used and the gas pressure becomes low, someone is always ready to suggest that there are gasoline-making plants along the natural gas main lines that make it a business to take out what little gasoline remains in the pipes, thus impoverishing the gas. It is shown that the gasoline itself is rich in heating values and taking it away, therefore, robs the gas. During periods of low pressure in winter when there is a shortage of gas, many good citizens have felt that they have been doing a service in behalf of the people in making complaints through the courts or legislative bodies against this "robbing of the gas," and because consumers have not received competent, scientific advice from disinterested sources, there have grown up needless misunderstandings and a waste of effort on negligible factors concerning the gas supply.

In an endeavor to settle the question for all time and for the benefit of the natural-gas-using public and the good of the entire country, the Bureau of Mines went thoroughly into the subject, with the result that the following conclusions have been drawn by Dr. Van H. Manning, Director of the Bureau.

In general, the decrease in heating value of natural gas from the removal of gasoline is greatly overestimated. One gallon of gasoline in the natural gas burned by the domestic consumer of gas is worth to him about 1¾ cents in heat value, while this same gallon of gasoline to the automobile owner is worth 25 to 30 cents. Taking the gasoline out of the gas, one gallon will equal 35 cubic feet of gas, but this is not taken from the consumer, because his gas is measured at

his home meter and he obtains 1,000 cubic feet of gas, irrespective of whether the gasoline is removed or not.

The Bureau of Mines has even reached the conclusion that the removal of the gasoline from the natural gas is a positive benefit to the consumer. Without these gasoline plants, great difficulty has been found by the gas companies in the condensation of the gasoline and water in the pipe lines, the gasoline and water disintegrating the rubber gaskets in the couplings, resulting in a large leakage of gas and the consequent lowering of the pressure. Therefore the taking of the gasoline is a safeguard to the consumer that he will not be without gas at serious times by reason of leakage. The installation of these plants eliminates most of the line trouble and gives better service to the public.

Furthermore, several hundred million gallons of gasoline of the highest fuel value and adaptability are added to the country's supply, which the Bureau avers would be practically wasted if not taken from the pipes.

There is still another reason, as the Bureau sees it, for extracting this gasoline from the natural gas. All gasoline obtained in this manner has what is known as a low boiling point; that is, it vaporizes easily, and this makes it valuable in starting automobiles, especially in cold weather. So valuable is this gasoline for this purpose, that refiners use all this supply in blending with straight-run gasoline with a higher boiling point, in order to produce a gasoline that the automobile can use without difficulty. The importance of this is seen in the belief that if the refiners were deprived of this gasoline from natural gas for blending purposes, the automobiles of the country would have more difficulty in using the gasoline now on the market. It is even possible that the absence of this high quality gasoline might precipitate a crisis in the gasoline market."

GASOLINE BY THE CHARCOAL ABSORPTION PROCESS*

"Two methods of extracting gasoline from natural gas—compression and oil absorption—are now used extensively, while refrigeration is used to a limited extent. The charcoal process, a recent development, operating on entirely new and scientific principles, compares most favorably with either of these methods. It produces higher yields and a better grade of gasoline. It does not require heavy initial installation costs and can be operated more cheaply. The apparatus has longer life and is not subjected to inefficiency due to wear. Its adaptability to field conditions is enhanced by the fact that it operates on either lean or rich gas at either high or low pressures.

This year there will be practically 300,000,000 gallons of gasoline produced from natural gas. Where the salable vapors in the gas are over a gallon per thousand cubic feet, it is possible to recover a considerable proportion by directly compressing and cooling the entire volume of gas. Where the salable vapors in the gas are not so plentiful, it has been the custom to resort to the oil absorption process, which is simply a method whereby the desirable vapors are concentrated by partial fractionation so that pressure and cooling may be effectively applied as in the original compression process. The gas is made to bubble or flow through absorbers where the gas comes in contact with a high-boiling mineral oil or naphtha which absorbs the heavier fractions in excess of the lighter ones. The oil or naphtha is then subjected to steam or direct heat to vaporize again the absorbed fractions so that they may later be condensed by cooling and compression.

Disadvantages of the Compression and Absorption Processes—There are several features of the present processes which are considered obnoxious by practical operators.

* By G. A. Burrell, G. G. Oberfell and C. L. Voress.

Both the oil absorption and compression systems require considerable pressure. The oil absorption may be used at low pressures, but it is not considered good practice because of the low saturations which must be adhered to. These high pressures are not only expensive to produce but mean large outlays for repairs and renewal of machinery. They also increase the danger of explosions.

Quite a little difficulty is experienced in marketing the product because of the large amount of so-called "wild" vapors which it contains. These vapors are the lower boiling fractions which have been absorbed and condensed in the higher boiling fractions by the compression, cooling and solvent action of the liquid. It has been apparent to many men for some time that a method whereby a sharp fractionation could be obtained would eliminate much of this trouble. Methods of hot blending and steam treatment have been used with varying success as a substitute for the original fractionation, but all admit that there is still much room for improvement.

The present oil plants are far from simple either in number of units or operation. Constant supervision is necessary if the oil plant is to be operated at as high a degree of efficiency as 75 per cent of gasoline extraction.

From the standpoint of pressures used, of quality of product, of efficiency of extraction, of simplicity of apparatus and operation, and of cost, a new process, one working on an entirely new principle, has been demanded.

Charcoal Absorption Process—The charcoal absorption process consists of bringing the natural gas into intimate contact with activated charcoal, in the capillaries of which the vapors are condensed and the dried gas allowed to return to the distribution lines. When a predetermined saturation of absorbed vapors has been attained in the charcoal, the gas is allowed to come into contact with a fresh supply of carbon. The vapors retained in the first mass of charcoal are then

evacuated by distilling off with superheated steam, condensed in water-cooled condensers, blended and stored preparatory to marketing. Fig. 125 is a flow sheet diagram of the plant.

Activated Charcoal—The charcoal best suited for the successful operation of the process is made from coconut shells by the steam activation process developed during and since the war. Charcoals made by other methods do not possess sufficient absorptivity to pay for the costs of recovery and therefore are of no use in this process. Even at the close of the war, the better grades of charcoal, those testing from fifty to sixty minutes by the accelerated chlorpicrin test,* had not been produced in quantity.

Any charcoal suitable for absorption of vapors from gas must be capable of readily condensing and retaining large quantities of liquid in capillary equilibrium with its vapor and at the same time offer a minimum resistance against recovery. It has been found when applied to gasoline production, if coconut charcoal is activated up to forty, fifty or sixty minutes for the absorption service time, that the retentivity factor tends to decrease above fifty minutes. The curves given in Fig. 126-2 A were obtained with our standard laboratory testing outfit, the glycerine distillation method being used in obtaining the data. It will be noted that there is not a great amount of difference in the maximums of the curves. The big difference is in their decrease in efficiency due to oversaturation. In other words, it is the retentivity function. Fig. 126-2 B shows the same curves corrected for gravity. The twenty-minute material shows a large lack of retentivity, probably due to the shallow capillaries. The fifty-minute material shows up best here, due no doubt to the capillaries being of the correct size to permit of selection a term which we shall discuss later. Fifty to sixty-minute charcoal will absorb from 10 to 15 per cent of its own weight and retain the salable vapors for later recovery.

* Arbitrary test used in determining the porosity of charcoal.

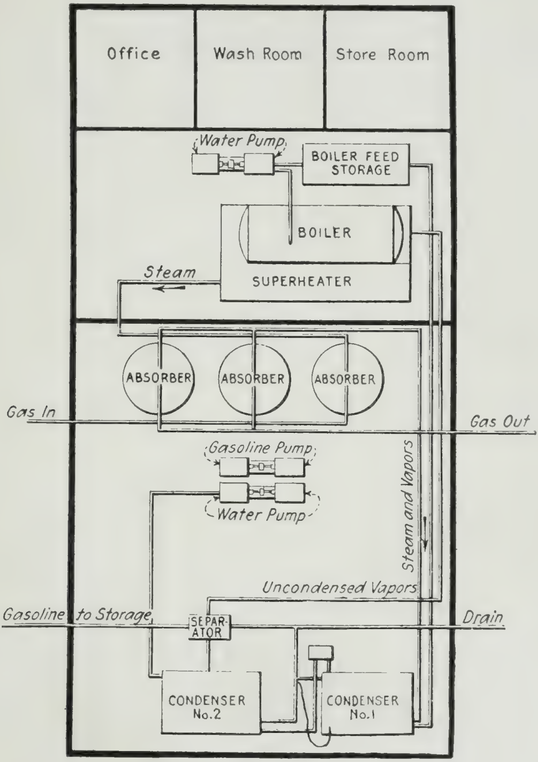


Fig. 125

One very essential feature that the charcoal must possess is what we term selective absorption. Natural gas consists of the gases and vapors of the paraffine hydrocarbon series, the higher members of which have an appreciable vapor pressure at the temperature of the gas. When the gas is first brought into contact with the charcoal the lighter, high-volatile vapors, such as ethane, propane, butane, etc., are absorbed in the capillaries, but as the saturation increases a selection or equilibrium adjustment takes place with the

result that these high vapor pressure and undesirable fractions pass out with the gas. The heavier fractions are thus isolated and can then be condensed after steam distillation without the use of high pressures. Regulation of the vapor tension of the final product is thus obtained by preventing the absorption of the higher boiling fractions.

The size of the granules of charcoal should be from 8 to 14 mesh. Smaller mesh material has slightly greater absorbing qualities, but the resistance to the gas passage rapidly increases as the size of the granules decreases. Gas flowing through a column of charcoal 5 ft. in depth at the rate of 40 cu. ft. per hour per sq. in. of base surface and flowing against atmospheric pressure will show a retardation of from 1 to 2 lb. due to the charcoal resistance.

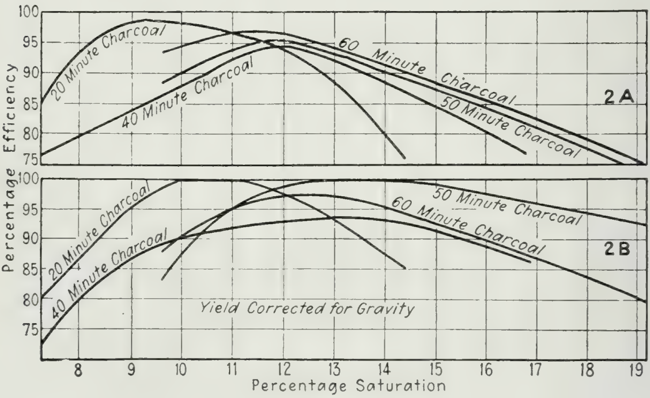


Fig. 126

Absorption—When natural gas first comes into contact with charcoal considerable heat is developed, which is the latent heat of vaporization from the condensing vapors. After a few minutes the temperature stops rising, which indicates that selection is taking place and the heat of condensation is being used to re-volatilize the highest condensed

liquids, which must be eliminated from the final product. Many investigators have ignored this phenomenon, and have stopped when no more heat evolution was noticeable, thinking that the absorption was complete. With gas rich in vapors we have observed a temperature increase of 60 deg. cent. in the charcoal due to the latent heat in condensation. This does not mean that the entire body of charcoal increased 60 deg. simultaneously. The heated volume travels in a zone in the direction in which the gas flows. When using a tube of charcoal 1/4 inch in diameter and 1 ft. in depth and passing rich gas at the rate of 10 ft. per hr., the heated zone is about 2 inches in depth.

Table 111—HEAT REQUIREMENTS*

Weight of gallon gasoline, lb.	5.5
Saturation of 13 per cent by weight required, lb. of charcoal	42.3
Specific heat of charcoal	0.3
Specific heat of gasoline	0.58
Latent heat of gasoline, B.t.u. per lb.	100
Average b.p. of gasoline, deg. fahr.	210
Highest temperature of distillation, deg. fahr.	400
Temperature of charcoal by saturated steam, deg. fahr.	230
Superheat (400—230), deg. fahr.	170
Superheat required for charcoal (42.3 × 0.3 × 170)	2,157
Heat to raise charcoal 60 to 230 deg. fahr.	170
Heat required to raise charcoal 60 to 230 (42.3 × 0.3 × 170)	2,157
Distillation of 60 per cent made without superheat.	
Heat required for gasoline distillation (60 to 230 plus latent heat) (5.5 × 150 × 0.58) + (5.5 × 100), B.t.u.	1,030
Superheat required for 40 per cent of gasoline distilled	411
Heat required for first 60 per cent distilled, B.t.u.	618
Total heat required to raise to temperature of superheat, B.t.u.	2,775
Total amount superheat required, B.t.u.	2,568
Theoretical amount of heat required, B.t.u.	5,343
Specific heat superheated steam 15 lb. 400 deg. fahr.	0.5
Superheat available per lb. of steam 0.5 × (400—230), B.t.u	85
2568 ÷ 85, lb. of water	30.21
Boiler feed water, deg. fahr.	200
Boiler heat required, (200 to 400 deg. fahr.), B.t.u. per lb.	1,089
Total amount boiler heat required (30.21 × 1089), B.t.u.	32,900*
Boiler hp. per gal. gasoline per day	0.045

* When the work first started steam consumption was much higher than this theoretical figure. Today, as a result of various economies affected it is very close to the theoretical.

The temperature of the charcoal at the beginning of the gas passage is not very important when using gas of low gasoline content. It quickly gains the temperature of the incoming gas. A loss of about 6 per cent in final recovery was experienced when tests were run with the initial temperature of the charcoal 300 deg. cent. However, the temperature of the inflowing gas is more important. Fig. 127 shows that the curve of recoverable efficiency is practically a straight line function of the temperature, other things being constant. This curve reaches its zenith at 300 deg. cent. Above that there is no *recovery* at all.

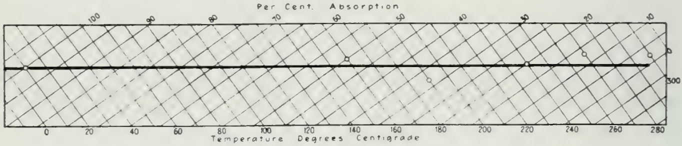


Fig. 127

The rate at which absorption takes place varies according to the richness of the gas mixture. For gas yielding 400 gallons of gasoline per million cubic feet, a rate of 40 cu. ft. per sq. in. of base surface in a 5 ft. column of charcoal is not too high a rate. Above this rate the back pressure due to the resistance of the charcoal itself begins to enter as a factor against higher rates. Fig. 128 presents graphically a series of experiments on rates under these conditions.

The volume of gas to be passed is determined by the nature of the product desired by the operator. If he desires a very volatile product, a low saturation of the charcoal must be had so as not to allow selection to eliminate too much butane, etc. If a staple low volatile product is desired, more gas is passed and the selection is carried as far as desired. This determines the nature of the product and will be discussed later. The volume to be passed to secure the maximum yields for the different grades of charcoal may easily be calculated by the curves given in Fig. 126.

Distillation—After absorption has been completed, it is necessary to expel the condensed vapors from the charcoal. This is done by blowing superheated steam directly through the charcoal. The superheat should be as high as local conditions will allow. There will be a decrease in fuel used per gallon of gasoline recovered, as the temperature of the superheated steam is increased up to the point where the radiation factor of the carrying lines and the efficiency factor of the heater itself become so large as to interfere. Local conditions affect this to a great extent. It will be found, however, that under ordinary conditions 250* deg. cent. may be maintained with good results.

The amount of steam required depends upon the percentage of the available heat that is utilized. The charcoal must be heated to 200 deg. cent. to dispel the heavier fractions of gasoline. This temperature also insures an active absorbent. The work done is mainly derived from the superheat. The accompanying calculations show that theoretically there are about 5,343 B.t.u. of heat required to produce a gallon of gasoline when the saturation is 13 per cent. Table 111 shows the heat requirements.

The question is repeatedly asked, "Does this steam distillation injure the charcoal for the other absorptions?" The steam distillation does not injure the absorptive capacity. In fact, it leaves it in a somewhat better condition than dry heating would conduce. The steam drives out gases and absorbed vapors at a somewhat higher temperature than will permit condensation. The first rush of cooling gas will displace the steam and the first condensation will be of the vapors in the gas. Fig. 129 (solid lines) shows the curves for two samples of charcoal, one of which was being used for the first time for gasoline absorption, the other being taken from the large plant after serving ninety-five absorptions and steam distillations.

*At the present time, (Aug. 1921), a temperature of 185 deg. cent. (365 deg. fahr.) is used.

A sample of charcoal which had been exposed to the air for a month was divided into two equal portions. One portion was heated to over 500 deg. cent. in an open vessel for more than two hours, and the other was treated to 300 deg. cent. with superheated steam. The portion treated with superheated steam exhibits an absorption curve which reaches its peak later and shows more retentivity than the dry heated sample. Fig. 130 (dotted lines) shows the curves for this experiment.

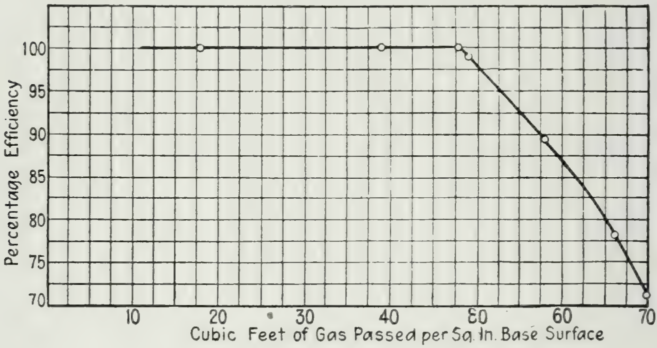


Fig. 128

Condensation—The gasoline vapors driven from the absorber with the steam may be condensed in any type of condenser. We prefer two water-cooled condensers in series. The cooling water around the first condenser can be circulated just swiftly enough to condense the major portion of steam and allow for its being trapped away without being cooled much under 100 deg. cent. In many localities this condenser may well be an air condenser with enough of the line jacketed to heat the boiler feed water.

The second condenser must be an efficient one. With cooling water at 15 deg. cent. or thereabout very efficient condensation will take place at atmospheric pressure.

The condensed gasoline and water flows from the condenser into a separating tank. If it is desired to blend the

final product with heavier naphtha to reduce its vapor pressure, that may also be done at this point. We prefer to blend with from 10 to 15 per cent of about 56 deg. B. naphtha.

An examination of the gasoline produced has brought to light the fact that the gravity and vapor tension of this gasoline is less than the gravity and vapor tension of that made from the same gas by either compression or oil absorption. Fig. 130 is a set of curves illustrating this point. There are several reasons for this. Conditions under which the condensation is made affect the character of the final condensate. It has already been noted that the charcoal process gasoline is condensed from a vapor-gas system under atmospheric pressure. This is in direct contract to the methods of condensation used in the compression or oil absorption processes, where the pressure generally ranges between 90 and 250 lb. When these gasolines are placed in storage or released from compression, evaporation begins to take place immediately and desirable fractions of the gasoline are carried away mechanically with the escaping undesirable wild vapors.

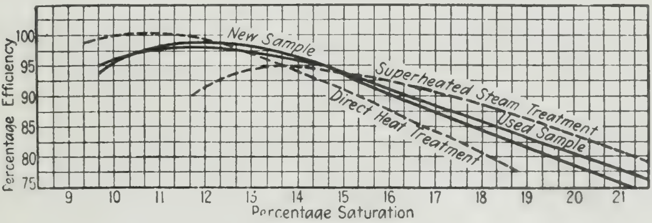


Fig. 129

The method by which the condensation is carried on is also an important factor in determining the character of the condensate. The charcoal process is a batch process. Consecutive distillations of a series of absorbers are made rather than continuous distillations of a single still. This drives out the lighter vapors first and makes possible the addition

of the blending naphtha to the fraction that actually needs blending. If there are any very volatile vapors left in the charcoal, they are driven out first by the lowest temperature and do not come into contact with the salable gasoline. By the oil absorption method, which is a continuous process, all fractions are driven out and carried to the compressors together. Here the salable vapors are condensed in the presence of the very volatile vapors under pressure, so that all the salable liquid must be saturated with wild vapors at the temperature and pressure used.

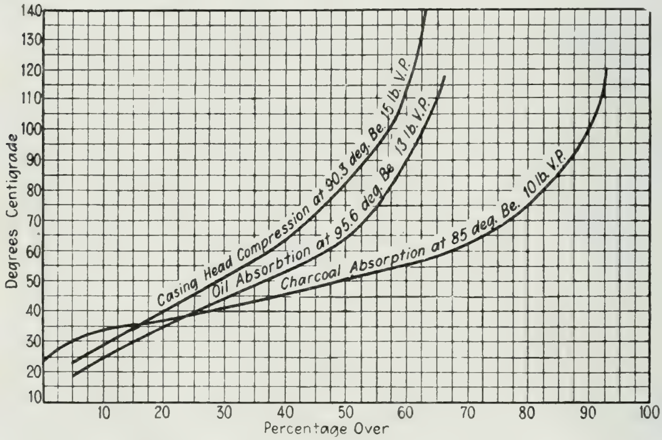


Fig. 130

A third explanation for the better quality is found in the method of absorption itself. We have already mentioned selective absorption, which gives clear-cut fractionation controlled by the operator. The wild vapors are practically all re-evaporated into the gas within the absorber itself, thus preventing their presence in the steam-distilled vapors and condensate later on.

Experience has shown that the product from charcoal absorption plants has 3 lb. less vapor tension and 10 deg. less gravity than gasoline made by an oil absorption plant operating on the same gas.

Table 112—WEATHERING TESTS

I—First Pair. Air Temperature 65 Deg. fahr.							
Time in hours	0	1	2	4	5	18	22
Oil absorption	1,000	995	970	950	940	856	850
Charcoal absorption	1,000	1,000	998	993	990	930	925
II—Second Pair. Air Temperature 65 Deg. fahr.							
Time in hours	0	1	2	4	5	18	22
Oil absorption	1,000	994	968	950	938	854	847
Charcoal absorption	1,000	1,000	998	994	990	930	927
III—Third Pair. Air Temperature 80 Deg. fahr.							
Time in hours	0	2	3	4	5	9	22	25
Oil absorption	1,000	965	945	935	922	890	830	828
Charcoal absorption	1,000	995	988	982	977	960	900	898

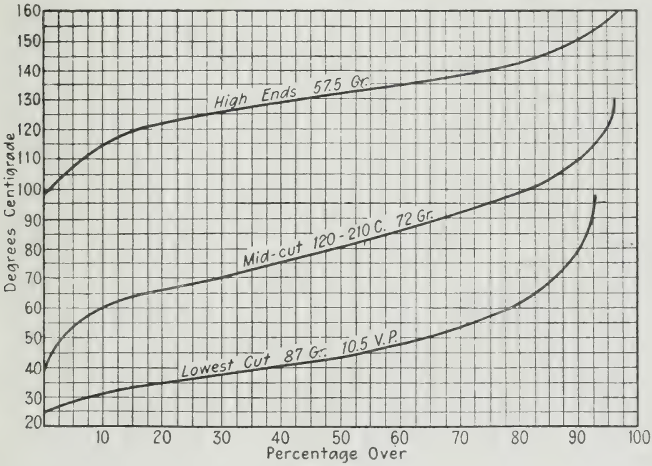


Fig. 131

Referring to Fig. 130, we see the results of applying the standard Bureau of Mines distillation test to the gasoline produced by the different methods. The initial boiling point of both compression and oil absorption gasoline is from 5 to 10 deg. below the initial boiling point of the charcoal gasoline. The final boiling points and the residue are practically the same. The curves of these distillations show that the big gain in yield is in the recovery of that product boiling between 30 and 70 deg. cent., or within the range of the pentanes and hexanes. About 73 per cent of the charcoal absorption gas-

oline is within this class. Approximately 33 per cent of the compression and 38 per cent of the oil absorption are condensed between these temperatures.

The same series of tests showed that 93 per cent of the charcoal absorption gasoline is recondensed after the standard Bureau of Mines distillation and approximately 66 per cent of the oil absorption and 63 per cent of the compression material were recovered. None of these samples had been blended before they were tested. The oil absorption sample had been made under a final pressure of 90 lb.

Fig. 131 is a curve showing the application of the Bureau of Mines distillation test to three different fractions of charcoal absorption gasoline. This brings out the fact that the fractionation was very sharp and even the first cut was quite staple.

The weathering losses of gasoline made by the charcoal process are very light. Table 112 shows three pairs of weathering tests, comparing samples of gasoline taken directly from the blender of a charcoal plant and gasoline taken from the storage tanks of an oil absorption plant, where it has been allowed to weather under about 3 lb. pressure for more than two weeks. All samples were blended with 12½ per cent naphtha 56 deg. B. Each pair was kept under the same atmospheric and temperature conditions.

After what has been said about quality, the reader may infer that the yield is being sacrificed. Such is not the case. A direct comparison between an oil plant and a charcoal plant operating on very lean gas showed that the oil plant averaged around 125 gallons per million cu. ft. of gas and had a weathering loss of 20 to 30 gallons before shipment. The charcoal plant produced an average of 203 gallons of high quality gasoline from this same gas on the same days. The reasons for this wide variation between the two plants are numerous. The problem of bringing every particle of gas into intimate contact with oil capable of absorbing the

commercial vapors has always been difficult. Many kinds of baffles and sprays have been tried with varying degrees of success. With an absorber packed with from 8 to 14 mesh charcoal there is no difficulty in getting proper contact for complete extraction.

The absorption of the vapors by a solid medium is governed by conditions entirely different from those governing the absorption by a liquid which depends on reduction of molecular area of the dissolved vapor. It is the capillaries of the charcoal which alter the vapor tension of the absorbed paraffine and make the absorption possible. The degree to which the capillaries are deepened and oxidized free from interfering compounds determines the absorptive capacity of any particular charcoal. However, difference in grades of carbon or any other substance which might be used for the framework of these capillaries is an important factor which must not be overlooked when studying the conditions governing the absorption of gasoline.

The absorption process is actually a modification of the compression process, which consists of concentrating the recoverable vapors before applying the compression. But by the compression method it is possible to condense only a certain part of each fraction included in the gas. This part is determined by the number of fractions present, by the percentage of the different fractions present and by the temperature and pressure employed. It is only a specific application of the partial pressure laws. The addition of air or any gas not condensible at the working pressures means loss in efficiency.

Plant—Suitable apparatus to practice the charcoal absorption process will include three essential units—viz., a power unit consisting of a boiler equipped with a superheater, an absorber unit consisting of at least three absorbers or charcoal containers, and a condenser unit consisting of cooling coils and a separation and blending tank."

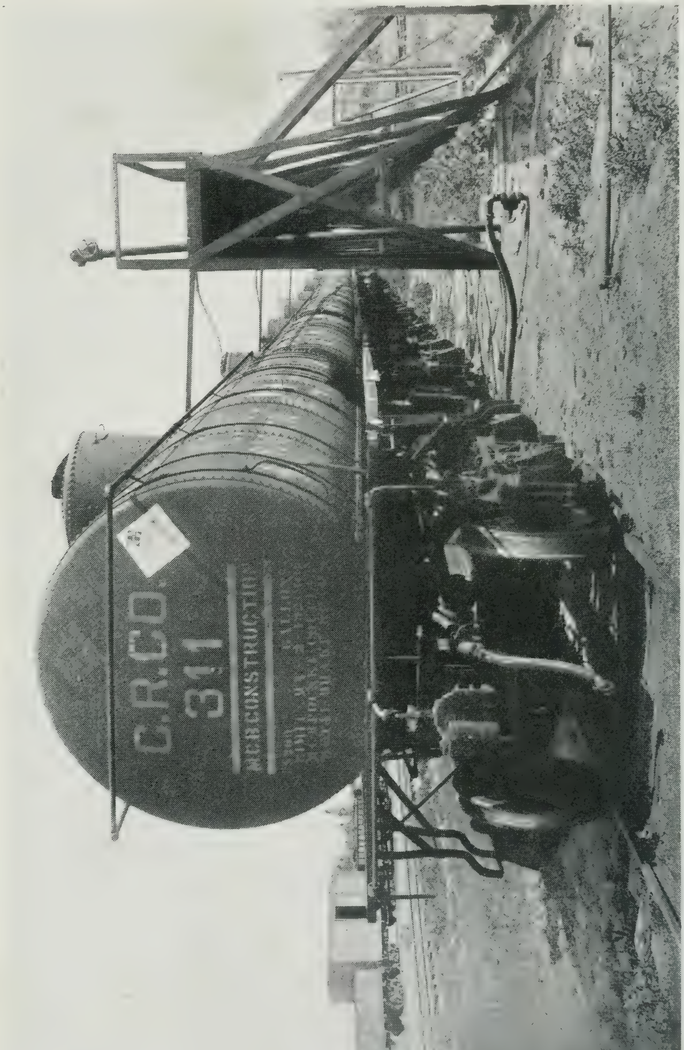


Fig. 132—GASOLINE LOADING RACK

PART FOURTEEN

Gasoline

PROPERTIES AND TESTING LIQUID HYDROCARBONS—TYPES OF GASOLINE—PROPERTIES OF GASOLINE—ANALYSIS BY DISTILLATION—BOILING POINT—VAPOR PRESSURE—GASOLINE RULES—HEAT VALUE OF OIL AND GASOLINE.

Actual standards of quality of gasoline seem to vary with advances in engine design, so that what was once decidedly poor gasoline can now be successfully used. Probably the limit of change has not been reached. The grades of gasoline now on the market do not necessarily represent future grades.

Gasoline—This name has been applied broadly to the lighter products derived from petroleum, ranging in gravity from 50 deg. B. to the high gravity products, 90 deg. B. and over, which are extracted from the still gases by the compression method.

There are two general grades of gasoline: the normal gasoline which exists naturally in petroleum; and the "cracked gasoline", formed by the decomposition of the heavier products. The normal gasoline has a low iodine absorption, whereas the gasoline produced by the cracking process has a high iodine absorption.

The examination of gasoline should include gravity test, temperature distillation, the determination of the sulphur, and the iodine absorption.

Normal gasoline should be water-white in color, of sweet odor, should evaporate without leaving any stain or appreciable odor, and the iodine absorption should be below 5 per cent. Normal gasoline is used, or rather should be used in all dry-cleaning establishments.

"Cracked" gasoline, as the name implies, is likely to fluctuate in properties. Speaking generally, and of its application to use in gas engines, it should show a low initial boiling point, and should have a final boiling point of not higher than 350 deg. fahr. As long as these conditions are fulfilled, the lowest gravity is the best product.

That fraction of b. p. 40 deg. to 70 deg. cent. obtained in the refining of Pennsylvania petroleum, consists largely of pentane and hexane. The grades of gasoline and benzine made from Pennsylvania petroleum vary in gravity from 56 deg. B. to 86 deg. B.; the eight grades usually marketed are as follows: 60, 62, 63, 64, 66, 68, 70 and 72 deg. B.

The gasoline used for automobile purposes varies from 60 deg. to 74 deg. B. The heavier gravities are extensively used for mixing paints and for blending with condensed gas gasoline; the lighter grades are employed in the manufacture of rubber cements and in illumination. Gasoline from California petroleum usually has a gravity of 60 deg. B.

There is some confusion in the use of the names benzine, gasoline and naphtha, but the best practice is to employ the term gasoline for any mixture of light hydrocarbons intended for use in any kind of vaporizer, i. e., to be gasified in a gas machine, gasoline torch, gasoline stove, or automobile carburetor.

Benzine—That fraction of b. p. 70 deg.-120 deg. cent. obtained in the refining of petroleum. Heptane (C_7H_{16}) is the principal constituent of the benzine from Pennsylvania oil. Totally distinct from the aromatic hydrocarbon benzene, C_6H_6.

Deodorized benzine, the light solvent of the "U. S. Pharmacopoeia," has a specific gravity of 0.638—0.660 at 25 deg. (82 deg.—89 deg. B.) and a b. p. of 45-60 deg. cent. The benzine of some American refiners—that used in the oilcloth and varnish industries—has a specific gravity of 0.729 (62 deg. B.); of others, 0.741—0.745.

Petroleum Spirit—A term which is variously used, but is sometimes applied to a petroleum distillate of a density of 0.71 to 0.74 and a boiling point of 90 deg. to 140 deg. cent. It is used as a solvent.

Some refiners have employed the term to include naphthas ranging in specific gravity from 0.679 to 0.745 (76 deg. to 58 deg. B.)

According to German practice, petroleum spirit used as a motor fuel should contain nothing, or at the very most 5 per cent boiling above 100 deg. cent.

Rhigolene—The most volatile liquid fraction obtained in the distillation of petroleum. It has a boiling point of 18 deg. cent. and consists largely of pentane (Kharirchkov, Nepht. Dielo, 1899, 170); its specific gravity is 0.60.

This petroleum ether was introduced for producing local anesthesia by freezing (Bigelow, Chem. News, 13(1866),244). In "aether anaestheticus Konig" four parts of rhigolene are mixed with one part of absolute ethyl ether.

The term rhigolene has also been applied to the product described under cymogene; specific gravity, 0.625 to 0.636. Crude naphtha from Pennsylvania petroleum yields about 0.1 per cent of such rhigolene.

Kerosene—A mixture of hydrocarbons whose average boiling point is about 450 deg. fahr., freed on the one hand from gasoline or naphtha and on the other hand from the heavy hydrocarbons that belong to gas oil and lubricating oil, which would make the oil act badly in lamps. Kerosene contains nonane (C_9H_{20}), decane ($C_{10}H_{22}$), etc., and is used as an illuminating oil. The following are the rules of the New York Produce Exchange relating to kerosene: "Refined petroleum shall be standard white or better, with a burning test of 110 deg. fahr. or upward, and of a gravity not below 44 deg. B., "United States Dispensatory" standard.

"The burning test of refined petroleum shall be determined by the use of the Saybolt electric instrument, and

shall be operated in arriving at a result as follows: In 110 deg. and upward, the flashing-points, after the first flash (which will generally occur between 90 deg. and 95 deg.), shall be taken at 95 deg., 100 deg., 104 deg., 108 deg., 110 deg., 112 deg., and 115 deg. In 120 deg. and upward, after the first flash, at 110 deg., 105 deg., 110 deg., 115 deg., 118 deg., 120 deg., 122 deg. and 125 deg. In 130 deg. and upward, every 5 degrees until burning point is reached."

Two well-known kerosenes from Pennsylvania petroleum possess respectively gravities of 48.5 deg. and 45 deg. and fire tests of 150 deg. fahr. and 175 deg. fahr.

Generally speaking, the burning oils manufactured in the United States are of the following grades: Fire test, 110 deg. fahr.; Abel test, 70 deg. fahr. Fire test, 120 deg. fahr. Abel test, 73 deg. fahr. Fire test, 150 deg. fahr. The last mentioned is nominally "water-white," and the others range in color from "prime-white" to "standard-white" (straw color to pale yellow).

TYPES OF GASOLINE

There are at present on the market types of gasoline produced by several general methods. These may be classified as follows:

1. "Straight" refinery gasoline.
2. Blended casinghead gasoline.
3. Cracked and blended gasoline.

"Straight" Refinery Gasoline—"Straight" refinery gasolines are produced by methods that vary somewhat in different parts of the country, but in general are similar. Crude oil is distilled in a fire still and a cut made when the gravity of the product reaches some predetermined mark. So-called crude naphtha, or benzine, is acid refined and steam distilled. Several products of different ranges of volatility may be produced, or the steam distillation may simply separate the product from the less volatile bottoms, which go into the burning oil stock.

"Straight" refinery gasolines are generally characterized by a low content of unsaturated and aromatic hydrocarbons, and by a distillation range free from marked irregularities.

Blended Casinghead Gasolines—"Straight" casinghead gasoline is too volatile for general use, and before being marketed, is generally blended with enough heavy naphtha to produce a mixture that can be used safely and is moderately cheap. In general, blended casinghead gasoline is characterized by a volatility range that shows a considerable percentage of constituents of low and of high boiling points, but a lack of intermediate products. Frequently, however, the blending is done in a manner difficult to detect, the natural gas gasoline being used in moderately small proportion with "heavy" straight-run naphtha in order to make a product having a desirable percentage of volatile constituents.

As regards its chemical properties, blended casinghead gasoline seems to be identical with the "straight" refinery products of the same distillation range. Characteristic physical properties of blended gasolines are due wholly to the details of blending.

Cracked or Synthetic Gasolines—Important factors in the present supply of gasoline on the market are the cracked or synthetic gasolines. These are being marketed in enormous quantities, largely, if not altogether, in the form of blends with "straight" refinery and casinghead gasoline.

Cracked gasolines are similar to "straight" refinery products in most physical and chemical properties, but differ chemically in containing varying percentages of unsaturated and aromatic hydrocarbons. It has been demonstrated that these constituents, if present in moderate proportion, do not decrease the value of a gasoline. Also, competent authorities generally concede that by proper engine equipment and adjustment it is possible to use unsaturated hydrocarbons in practically unlimited proportion, although extensive experimental proof of this latter point does not seem to be available as yet.

PROPERTIES OF GASOLINE

The essentially desirable properties of gasoline may be summarized briefly as follows:

(1) The gasoline should not contain too large a percentage of highly volatile products, which tend to cause large evaporation losses and excessive danger in handling and storage, but should have sufficient volatile constituents to permit starting an engine under reasonably unfavorable conditions without preheating.

(2) The gasoline should not contain any considerable percentages of heavy or nonvolatile constituents, which after atomization into the engine cylinders can not be completely vaporized and burned.

(3) The gasoline should not contain a material which after combustion leaves a residue that collects in the motor.

(4) The gasoline should be free from substances that attack metal, either before or after combustion. Unremoved acid (used in refining) falls under this head.

(5) Neither the gasoline nor its products of combustion should have a strong or markedly disagreeable odor, because of this being objectionable to users of automobiles.

(6) The gasoline should be free from noncombustible material, such as water, sediment, acid, etc.

These stated requirements are simple in principle and are almost axiomatic. The chief problem is to fix limits, defined by actual tests, that will satisfy the desirable conditions.

Color—Color is of some importance, because it serves as an index of other qualities. Properly refined gasolines are water white, and hence it seems desirable to include a color requirement in specifications for gasoline. It does not, however, seem necessary to employ a test involving any sort of a tintometer, as the rough-and-ready method of looking through the bottom of a 4 ounce sample bottle is adequate.

Odor—Gasoline should be free from rank and disagreeable odors, as these cause discomfort of users, especially if the odor has a tendency to cling to the clothing. It is, of course, impossible to fix any definite standard for odor as to either quality or strength. The older requirements demanded the sweet, pleasant odor characteristic of high-test uncracked distillates. With the present necessity of using cracked gasoline this requirement has become impossible and the requirement of odor must be left in rather indefinite form.

Foreign Matter—Gasoline should obviously be free from water and other foreign matter. Water is seldom present in gasoline and is always easy to detect, as the two liquids are mutually insoluble.

Acidity—Obviously, too, gasoline should not contain any acid from the refining process. This, however, seems to be a failing from which market products are largely free. Acidity may be detected by shaking a sample of the suspected gasoline thoroughly with a small quantity of water and testing the water with blue litmus paper.

Heating Value—No data is at hand to show the effects of calorific power on the usefulness of a gasoline. However, the actual variations in calorific power for different kinds of gasoline seem to be relatively small, and as the mechanical energy developed in the engine is only a fraction of the heat produced, these variations may be regarded as negligible. Some recent experiments have shown that gasolines of widely differing physical properties varied only by a maximum of 2 per cent in calorific value per unit weight.

Unsaturated Hydrocarbons—The effect of unsaturated hydrocarbons on the properties of gasoline is another matter that has not been worked out completely. As already stated, there is conclusive evidence showing that gasolines containing moderate percentages of unsaturated hydrocarbons can

be used with entire satisfaction, but it is not yet definitely established that the presence of unlimited proportions of these constituents causes no disadvantage.

In view of present market conditions it does not seem desirable to emphasize any requirements that may interfere with the development of cracking processes, as this now seems to offer the greatest possibility of conserving the country's petroleum resources.

The Bureau of Mines is preparing to publish the results of a study of the comparative advantages of various analytical methods of determining degrees of unsaturation. This study has shown that the acid-heat test, largely used by refiners, is little better than qualitative, and determination of iodine absorption by the Hanus method, though accurate and fairly rapid, requires some little skill of manipulation on the part of the operator. If experimental details are properly regulated, the measurement of the percentage absorbed by ordinary sulphuric acid seems on the whole the most desirable method.

Specific Gravity—Specific gravity in itself is of very slight significance in determining the properties of gasoline. It may serve as an index of other properties, particularly volatility, if knowledge is at hand regarding the source and method of production of a gasoline. The determination of gravity has been and probably always will be one of the most useful tests that the refiner employs, but it is of but little value to the analyst who does not possess sufficient additional information to make proper interpretation of gravity results.

Methods of determining gravity are too well known to need discussion. The type of instrument chosen may be hydrometer, displacement balance (such as Westphal), or a suitable pycnometer, according to the quantity of gasoline to be tested. Of these instruments the hydrometer is most convenient, the pycnometer least convenient. The accuracy of the determination should be within 0.1 to 0.2 per cent.

Gravity is generally expressed as the ratio of the densities of oil and water at the temperature of 60 deg. fahr.

Volatility—Volatility is the basic property that determines the grade and usefulness of a gasoline. Unfortunately its influence is not simple enough for adequate discussion in a few words, chiefly because the advantages and disadvantages of various characteristics of volatility are so balanced that no one characteristic can be said to be either entirely desirable or entirely undesirable. For example, the presence of considerable percentages of low-boiling constituents in gasoline would seem desirable in that they permit easy starting of a cold engine. Against this advantage are the high prices of such gasolines and the considerable evaporation losses, the latter tending to increase the danger in storage and handling.

General consideration of the numerous factors involved has led to the following conclusions regarding the desirable characteristics of the volatility of motor gasoline.

Gasoline should contain a moderate but not excessive proportion of low-boiling constituents, enough to permit easy starting of a cold engine, but not enough to make evaporation losses excessive.

Gasoline should have a total volatility range wide enough to include constituents that have a high, but not too high, boiling point. For economic reasons affecting both the individual user and the country as a whole, this volatility range should be such that the gasoline contains the largest possible percentage of the original crude oil. It should not, however, be wide enough to exceed the limits of the vaporizing power of the automobile engine.

These two factors are not the only ones involved in the problem of volatility limits; but if properly attended to they generally take care of other essential features, such as "flexibility," freedom from carbon deposition, and development of maximum power.

Discussing the essential properties of gasoline is relatively easy when only general principles receive consideration. Also, it is relatively simple to outline rational specifications for a grade of gasoline that under most conditions will satisfy the great majority of users. In other words, it is easy to describe in general terms the desirable limits of volatility and reasonably easy to give figures that come safely within the limits. To define the real limits instead of stating figures safely within them is, however, a totally different problem, one involving a number of factors that can not be disregarded. In general, however, it may be said that the upper limit of volatility is fixed by average present-day motor construction.

The low limit, or rather the percentage of constituents volatile enough to insure ready starting of a motor, varies with the design of the engine, and also with existing temperature conditions. It is obvious that to "start" satisfactorily, gasoline must contain more low-boiling constituents in the winter than in the summer, and more in cold climates than in mild. All of these considerations emphasize the impossibility of fixing temperature limits that will in all cases economically and satisfactorily define the product "gasoline." In general usage "gasoline" is thought of as something that will start an automobile engine and keep it going when started. The "goodness" of the gasoline from the point of view of the average user depends largely on the ease of starting and only in a minor way on the possible mileage per gallon or on freedom from carbon deposition.

ANALYSIS BY DISTILLATION

"**Distillation Methods**—The distillation methods now generally used in the laboratories of refiners vary in some details, but are mostly modifications of the Engler-Ubbelohde method. This method has various basic deficiencies and is inadequate for the analysis of crude oil, as has been

shown by some recent experiments of the Bureau of Mines.* It is possible that a modification of the Hempel method employed by the bureau for this work and also for a recent study† of the properties of gasoline, might be more satisfactory for general testing purposes. However, the Engler-Ubbelohde methods are so widely employed that they seem as little likely to be abandoned as the Baume gravity scale. For examining gasoline the method is more nearly adequate than for examining crude oil, because all that is necessary is a uniform basis of comparison for different gasolines.

The use of the various modifications is determined chiefly by the amount of information sought. In some laboratories it is customary to determine only the initial boiling point and the 'end' or 'dry 'point, the latter being the highest temperature registered by the thermometer at the end of the distillation. The initial boiling point is variously taken, but generally the temperature is read when the first or the fifth drop falls from the end of the condenser.

Sometimes analyses are more elaborate and the temperature is read for each 5 or 10 per cent distilled and, if desired, the gravities of the various fractions are determined.

Laboratory practice differs in respect to the size of the distilling flask and the quantity of gasoline taken as an original charge. The original Engler flask was designed to hold 100 cc. of oil. When only initial boiling-point and end-point determinations are to be made this size is generally used. However, there are certain disadvantages from the use of so small a quantity. When percentage cuts are to be made many laboratories use larger flasks of such dimensions as to give about the same proportionate degree of fractionation as is attained by the original 100 cc. flask. Charges of 200 cc. and of either 400 or 500 cc. are often distilled,

* Rittman, W. F., and Dean, E. W., The Analytical Distillation of Petroleum, Bulletin 125, Bureau of Mines, 1916, pp. 1-75; Jour. Ind. and Eng. Chem., vol. 7; 1915, pp. 185-195, 754-760.

† Rittman, W. F., Jacobs, W. A., and Dean, E. W., work cited.

Fig. 133—RUNDOWN TANKS, DRUMRIGHT REFINERY

the latter being taken when the specific gravities of small fractions are to be measured with hydrometers.

In formulating specifications the conditions of distillation must be exactly defined in order to permit equitable settlement of disputes. It is probable, however, that for the distillation of gasoline the results of all of the open-flask methods agree pretty closely, and it is by no means necessary for the testing laboratories of refineries to discard present methods unless products approach permissible limits very closely.

The advantages in using the various sizes of charges are more or less evenly balanced. The use of 400 or 500 cc. is probably most convenient when it is desirable to measure the gravities of fractions. The Bureau of Mines has in the past favored 200 cc. for its own experiments because the volume of the distillates permitted gravity measurements with the Westphal balance, which has been employed instead of the hydrometer.

In the present analytical methods for gasoline it has not seemed necessary either to separate fractions or to measure gravities. Hence one of the chief advantages resulting from the use of large original charges vanished. There remain certain mechanical advantages, particularly as regards minimization of experimental error, but it finally seemed that for the needs of the present work the 100 cc. charge is most desirable.

The sample of gasoline to be examined can be shipped in the convenient 4 ounce sample bottle, which is in common use in the petroleum industry. In addition, an experiment can be made quickly, and the results are accurate enough for general purposes. The chief advantage, however, is that the method is already so standardized that it is not an innovation.

The American Society for Testing Materials has had occasion to adopt a distillation method for the petroleum products used as turpentine substitutes, and this method, with one or two minor modifications, seems highly desirable for use with gasoline. The apparatus is standard and can be readily purchased; the details of manipulation are simple and yield satisfactory results. The method and apparatus are described in detail on a later page, but a general description seems desirable here. The method involves the use of a thermometer of standard dimensions, a standard 100 cc. Engler flask, and an ice-cooled metal condenser tube set at an angle of 75 deg. from the perpendicular. The gasoline is distilled at standard rate of 4 to 5 cc. a minute, temperature readings being made as each 10 per cent has distilled and when the end or dry point is reached. The latter is the highest temperature read on the thermometer after the flask boils dry.

It has been customary in the past to read as the initial point, the temperature at which the first drop falls. This point is difficult to measure accurately, and there seems to be no advantage in using it instead of the more convenient 10 or 20 per cent mark. It seems that the gasoline should be defined by four points, which may conveniently be the 20 per cent mark, the 50 per cent mark, the 90 per cent mark, and the dry point. Some controversy has arisen as to the desirability of a 90 per cent temperature instead of the 95 per cent temperature. The former has the advantage of greater ease of accurate determination. The latter is preferred by some chemists, seemingly on general principles, without very definitely founded evidence. It is thought that by using the 90 per cent temperature and the dry point all needs are met, and experimental difficulties are avoided.

Satisfactory figures for these points insure the following desirable qualities of a gasoline:

(a) Enough moderately low-boiling constituents to permit easy starting of a motor;

(b) Not enough low-boiling constituents to cause undue tendency toward evaporation losses;

(c) Fairly uniform boiling range and not too great a percentage of constituents boiling at higher temperatures;

(d) Only a very small percentage of constituents of very high boiling point. In other words, not too high an end point.

Requirement b, which is satisfied by placing the lower limit for the 20 per cent mark, is introduced for the purpose of making a gasoline reasonably safe and free from evaporation losses. It is a limit that is not likely to be overstepped, on account of commercial conditions."*

Distillation Apparatus — The distillation method prescribed is approximately that recommended by Subcommittee XI of Committee D_1 of the American Society of Testing Materials.†

The two noticeable points of variation are the method of reading temperatures against fixed percentage points and the use of a thermometer of lower range. The method of the American Society for Testing Materials is proposed for the analysis of turpentine substitutes, which are petroleum products of higher boiling range than gasolines.

The apparatus used in the distillation should be as follows (see Fig. 134):

Flask—The flask used shall be the standard 100 cc. Engler flask, described in the various textbooks on petroleum. The dimensions are as follows:

* Tech. Paper 166, Bureau of Mines.

† Am. Soc. Test. Mat. Year Book for 1915, pp. 568-569, Part I, Committee Reports, 1916, vol. 16, pp. 518-521.

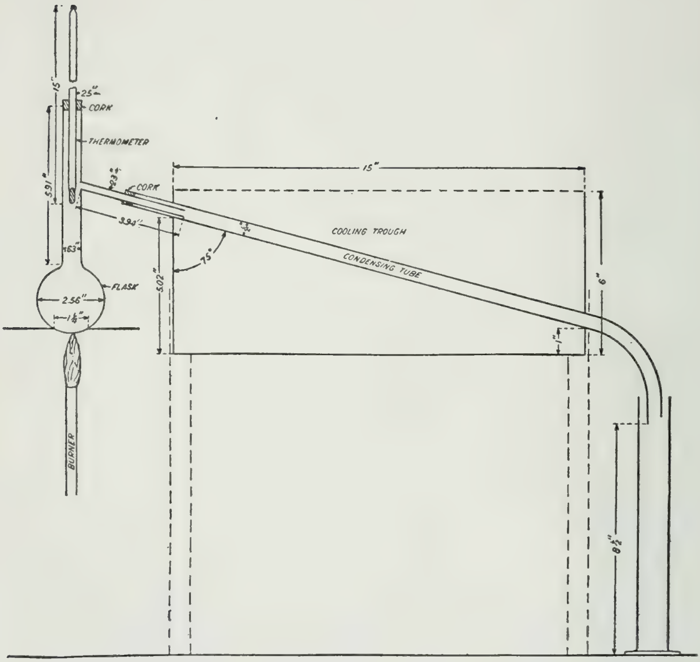


Fig. 134—DISTILLATION APPARATUS

DIMENSIONS OF FLASK

Dimensions	Cm.	Inches
Diameter of bulb	6.5	2.56
Diameter of neck	1.6	0.63
Length of neck	15.0	5.91
Length of vapor tube	10.0	3.94
Diameter of vapor tube	0.6	0.24

Position of vapor tube, 9 cm. (3.55 inches) above surface of oil when the flask contains its charge of 100 cc. The tube is approximately in the middle of the neck.

The flask shall be supported on a ring of asbestos having a circular opening 1¼ inches in diameter; this means that only this limited portion of the flask is to be heated. The use of a sand bath is not approved.

Condenser—The condenser shall consist of a thin-walled tube of metal (brass or copper), ½ inch internal diameter and 22 inches long. It shall be set at an angle of 75 deg. from the perpendicular and shall be surrounded with a water jacket of the trough type. The lower end of the condenser shall be cut off at an acute angle and shall be curved down for a length of 3 inches. The condenser jacket shall be 15 inches long.

Thermometer—The accuracy of distillation primarily depends on the accuracy of the thermometer and on this account the instrument should be so defined that the results of different analysis may check. The thermometer described in the report of the American Society for Testing Materials is not adapted for use with gasoline, its range being unnecessarily high and the lower temperatures being difficult to read because of interference from the cork in the neck of the distillation flask.

The present discussion does not deal with the details of temperature measurement but simply indicates requirements that should be met and will insure that the maximum pos-

sible variations in thermometer readings at different analytical laboratories can not exceed 1 deg. or 2 deg. cent.

Briefly, the thermometer should be an accurate "nitrogen-filled" instrument with a short bulb (length 10 to 15 mm., 0.39 to 0.59 inch) and with the mark for 35 deg. cent. (95 deg. fahr.) at a distance between 100 and 120 mm. (3.94 to 4.73 inches) from the top of the bulb. The thermometer should be scaled for total immersion.

The above requirements insure that almost always the lowest temperatures registered may be read above the cork of the distillation flask, and variations because of the so-called "stem correction" will always be practically the same. The stem correction should not be applied, but it should be understood that results of distillations are expressed in terms of thermometer readings, not of actual temperatures. The use of partial-immersion thermometers is not recommended for distillations, as these instruments are no more likely to agree with one another than are the more common total-immersion thermometers.

The following specification for a gasoline distillation thermometer is offered so that the prospective purchaser may be able to state definitely what he requires and by so doing obtain a satisfactory instrument. The specification has been submitted to several manufacturers of thermometers, who state that it insures the obtaining of a satisfactory high-grade instrument without imposing on the maker unnecessary and troublesome restrictions that increase the cost.

Specifications for Gasoline Distillation Thermometer—The thermometer should be made of selected enamel-backed tubing having a diameter between 5.5 and 7 mm. The bulb should be of Jena normal or Corning normal glass; its diameter shall be less than that of the stem and its length between 10 and 15 mm. The total length of the thermometer should be approximately 380 mm. The range should cover 0 deg. to 270 deg. cent., with the length of the graduated

Fig. 135—STORAGE TANKS

portion between the limits of 210 and 250 mm. The point marking a temperature of 35 deg. cent. should be not less than 100 nor more than 120 mm. from the top of the bulb.

The scale should be graduated for total immersion. The accuracy must be within about 0.5 deg. cent.* The space above the meniscus must be filled with an inert gas; such as nitrogen, and the stem and bulb must be thoroughly aged and annealed before being graduated.

All material and workmanship must be of the best. The scale shall be marked for single-degree intervals. Each tenth degree shall be numbered and each fifth degree distinguished by a longer mark.

Method of Distillation—The flask connected with the condenser shall be filled with a 100 cc. charge of gasoline which shall be measured from a 100 cc. graduated cylinder. The same cylinder may be used without drying as the receiving vessel for the distillate. Heat shall be applied to the flask in regulated degree, care being taken that the whole distillation from beginning to end shall proceed at a rate of not less than 4 nor more than 5 cc. a minute. Readings of the thermometer shall be made as each 10 per cent distills.

The dry point or highest temperature reading at the end of the distillation shall also be recorded. The distillation loss shall be determined by adding the percentage of residue in the distilling flask, after cooling, to the percentage of total distillates held in the receiver. If the distillation loss is over 3 per cent, a check distillation shall be made, as excessive loss may indicate that the rate of distillation at the beginning was too rapid. In case the magnitude of the loss is confirmed this fact is of importance in indicating that the gasoline contains very volatile constituents, particularly those derived from added casinghead gasoline.

* If desired, a Fahrenheit thermometer may be obtained on these specifications by substituting Fahrenheit equivalents for the several Centigrade marks.

The condenser trough shall be filled with a mixture of cracked ice and water (not dry cracked ice), and during the distillation sufficient ice shall be kept in the trough to prevent the temperature of the cooling water exceeding 8 deg. cent. (46 deg. fahr.)

If distillations are made at high altitudes or when barometric pressures are low, allowances may be made for this factor. In general, recording the barometric pressure read at the time of the distillation will suffice and it is recommended that whenever there is possibility of dispute over the results of a distillation this should be done.

The thermometer bulb should be covered with a thin film of absorbent cotton; this keeps the glass always wet with the condensate from the vapor and thus prevents possible fluctuations in the temperature. It also tends to prevent superheating of the bulb at the end of the distillation and thus makes possible an accurate determination of the dry point.

The whole procedure is relatively simple but involves certain details of manipulation of more or less importance. The use of apparatus at least approximately as described is essential, although the method is such that no considerable discrepancies will result if the apparatus is not exactly standard. The chief source of difficulty is the rate of heating. It is of course desirable to bring the initial charge up to the boiling point as rapidly as possible in order not to waste time, but unless care is taken the distillation will start too rapidly and there will be losses in the form of uncondensed vapor. In consequence the actual percentages will be higher than those read and the temperatures may likewise be noticeably high. If, however, the distillation loss is not permitted to exceed the stated amount this difficulty can be avoided. In case the gasoline to be tested contains considerable proportions of constituents difficult to condense, the condenser trough may be filled with a freezing mixture

____________REFINING COMPANY LABORATORY

Record of Distillation Tests: *100 CC*

Sample from *P R S X—111*

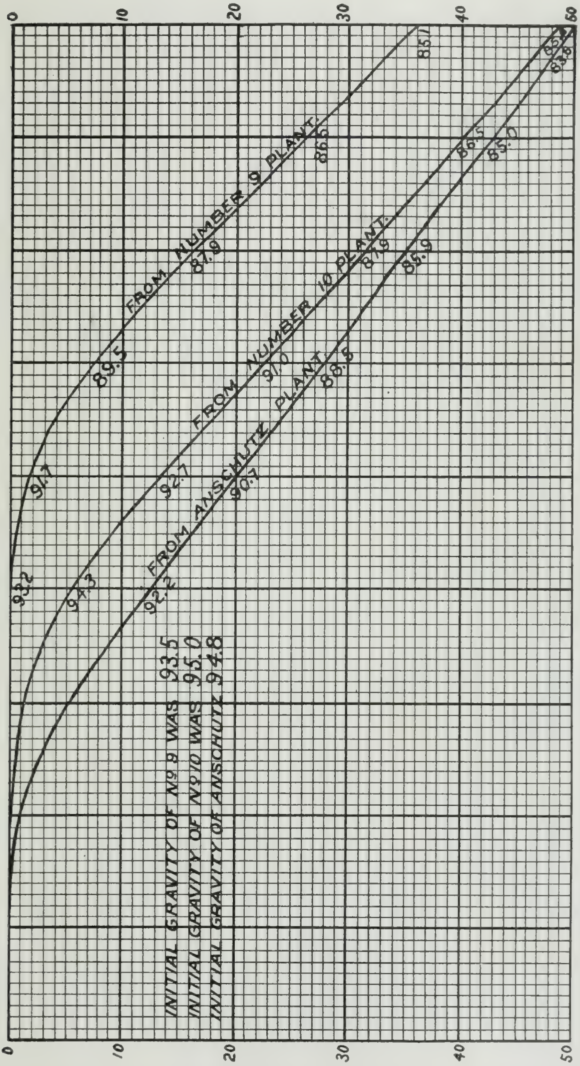
Grade *60—61 Gaso.*

Gravity *60.5* Started at *68°C. / 154° F.*

Per Cent.	C. Temp.	F. Temp.	Grav.	Remarks
10	*90*	*194*		
20	*97*	*206*		*25% @ 101°C./213*
30	*104*	*219*		
40	*110*	*230*		*40% @ 110°C.*
50	*115*	*239*		*87% @ 150°C.*
60	*122*	*251*		
70	*129*	*264*		
80	*140*	*284*		
90	*156*	*312*		
97%	*179*	*354*	*Dry*	

Date *5/21/17*

Fig. 136—RECORD FORM OF DISTILLATION TEST MADE ON A SAMPLE FROM A CAR OF GASOLINE



Per cent loss for different boiling points

Fig. 137. BOILING POINTS IN DEGREES FAHRENHEIT, GRAVITIES OF CASINGHEAD GASOLINE AT DIFFERENT BOILING POINTS SHOWING PERCENTAGE OF LOSS

and the receiver also kept cooled. If this is done, it is desirable to measure out the original charge at the temperature of this freezing mixture in order to avoid discrepancies due to changes of volume with temperature."

BOILING POINT.

From the time gasoline is released from the accumulator tanks, it boils until it reaches the temperature of the surrounding tank. As it boils, the boiling point rises steadily. If the boiling stops at any time due to any drop in temperature in the surrounding tank, it always begins to boil just where it left off when there is a rise in temperature. Boiling is usually most pronounced from 10 a. m. to 4 p. m., i. e., during the hot period of the day.

The air first starts to come out of the gasoline when it is heated and care must be taken not to mistake the small air bubbles for gas forming. As soon as the bubbles begin to come up repeatedly and grow larger as they come near the top the boiling point should be taken. Sometimes when the boiling point is taken the liquid will not begin to bubble until it has reached five or ten degrees higher than the true boiling point. This seems to be the case when the liquid is exceedingly pure and clean.

Boiling is best started from a point or particle. If no rough surface or point is present, the boiling often fails to start at the proper time. To insure getting the right boiling point, a little pebble or a little fresh earth should be put in to the sample before the test is taken.

Boiling Point Test on Casinghead Gasoline*—Investigation has been made as to the relation between the initial boiling point and vapor pressure, tests being made of casinghead and refinery gasolines.

* By Charles P. Beistle, Chief Chemist, Bureau of Explosives.

The vapor pressure tests were made in the usual manner, making corrections for the initial temperature. The initial boiling point was determined by placing the gasoline in a glass tube approximately 7/8 inch in diameter. Several glass beads were placed in the bottom of the tube, and the tube and contents were suspended in an outer vessel which was filled with water a few degrees warmer than the gasoline in the tube. The temperature of the water was gradually increased until the gasoline in the tube commenced to boil. The temperature of the gasoline was then observed. The first bubbles given off by the gasoline were not considered as evidences of boiling, as these bubbles were exceedingly small and did not materially increase in size from the time of their formation at the bottom of the tube, until they broke at the surface of the liquid. The temperature at which the bubbles first showed an increase in size, from the time of formation to the time of breaking, was called the initial boiling point. With a little practice this point can be determined within 2 degrees in a casinghead gasoline, and within about 5 degrees in an ordinary refinery gasoline.

The tests of casinghead gasoline were with one exception made at the compression plants or loading racks, and the boiling points reported were in every case the result of at least two closely agreeing tests. The gasolines tested and the results obtained were as shown in Table 113.

In developing the vapor pressure test it was found that very great differences in pressures were produced by variations in the initial temperature of the gasoline. To compensate for these variations it was found necessary to vent the test vessel at some fixed temperature, which was chosen at 70 deg. fahr. It was afterwards found necessary to make a further correction for low initial temperature by making the following deductions from the observed pressure:

Initial temperature	50–59 deg. fahr.	deduct	1 lb.
“	“	40–49 deg. fahr.	“	2 lb.
“	“	Below 40 deg. fahr.	“	3 lb.

These corrections make an allowance for the low initial temperatures of casinghead gasoline. In addition to this there is already an allowance made during the winter months by having the vapor pressure test made at 90 deg. fahr., instead of 100 deg. fahr. If the vapor pressure test is retained at all, the limit should be 10 lb. pressure at 100 deg. fahr. throughout the year.

In the original adoption of the vapor pressure test it was the idea that the test would limit the material shipped in ordinary tank cars, to a degree of risk equivalent to that involved in the shipment of the lightest and most volatile refinery gasolines. With casinghead gasoline or casinghead blends this has not been wholly accomplished, as it is evident that a gasoline of very low initial boiling point is more hazardous than one of normal boiling point, irrespective of any question of vapor pressure. The venting of the test apparatus at 70 deg. fahr. while absolutely necessary, to get any uniformity of results with the pressure test, evidently causes a material loss of gasoline of very low boiling point. Hence the results obtained are misleading.

Table 113

Kind of Gasoline	Maker	Corrected Gravity deg. B.	Initial Temp. deg. fahr.	Press. at 70 deg. fahr.	Corrected Press. at 90 deg. fahr.	Initial Boiling Point deg. fahr
Casinghead.	A	64	34	8½ lb.	10 lb.	55
Casinghead.	B	72.2	38	9½ lb.	12 lb.	40
Casinghead.	C	62	46	3 lb.	4 lb.	70
Refinery ...	C	61.1	53	....	1 lb.	140
Casinghead.	D	71.9	32	11 lb.	15½ lb.	44
Casinghead.	E	63	46	4½ lb.	4¼ lb.	80
Casinghead.	E	66.5	40	5 lb.	9 lb.	55
Casinghead.	F	70.5	34	10½ lb.	15 lb.	40
Casinghead.	G	74.9	46	5 lb.	5 lb.	103
Refinery ...	H	85.7	30	7½ lb.	6½ lb.	80
Refinery ...	H	60.8	40	4¾ lb.	2 lb.	145

The vapor pressure test is liable to great variations due to slight differences in manipulation, and depends also on the accuracy of a spring gauge. These gauges while presumably accurate when made, readily get out of adjustment; and inspection in the field has shown a large number of gauges in every day use for testing gasoline, to be very inaccurate.

The ordinary tank car is not designed to carry high internal pressures, especially with regard to the bottom valve, and the dome cover fastening. That the gasoline permitted under the existing tests and regulations, and the regular "60 lb." tank car are more or less incompatible, may be inferred from the disproportionate number of accidents in the transportation of casinghead gasoline.

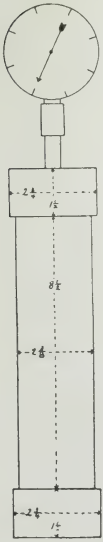


Fig. 138

With a view to obtaining greater safety in transportation and greater accuracy, and simplicity in tests the adoption of a minimum initial boiling point of 70 deg. fahr. is recommended for all inflammable liquids in ordinary tank cars.

Vapor Pressure Apparatus — Apparatus shown in figure 138 consists of iron or steel pipe of two inch size with caps screwed on ends. Upper cap has 0.25 inch nipple screwed in and is connected by a coupling to a 3 inch 30 lb. pessure gauge. Gauge is known as Inspectors' Gas Gauge. All joints must be entirely tight. Joints between large pipe and caps are best sealed with solder. Approximate external dimensions are indicated on sketch. In addition to apparatus indicated in test, there is also required a tin cylinder for filling test tube 12 by 3 inches that can be slipped over outside of tube for convenience in carrying when not in use. The tin cylinder is provided with

a lip for pouring. A small tin cover 0.75 inch deep, fitting over the bottom of the tin cylinder may be removed and used for measuring off one tenth capacity of test tube. A small tin funnel 2.5 inches in diameter with stem 3 inches long and three sixteenths inch in diameter should be used.

Vapor Pressure Tests*—Remove the gauge from the tube and fill tube to 90 per cent of its capacity. Fill tube preferable by lowering it into the storage tank in upright position by means of a cord or wire. Leave the tube entirely immersed for several minutes, withdraw it and pour off sufficient liquid so that tube will contain 90 per cent of its capacity. A small measure having capacity of 10 per cent of the test tube should be used for that purpose.

In case it is impracticable to lower the tube into the storage tank, draw the liquid off into the vessel of capacity about equal to the test tube. Pour liquid into the test tube until about half filled. Shake tube and contents gently in order to bring both to the same temperature. After standing for several minutes, pour out all the liquid from the tube. Draw another sample from the storage tank into the cylinder and pour through funnel into the tube until the latter is entirely full. Withdraw $\frac{1}{10}$ as before. Screw gauge tightly into position using a little liquid shellac on joint to insure a tight fit.

Immerse the tube in water at temperature of 70 deg. fahr. and allow it to remain for 5 minutes. Then remove it from the water and unscrew the gauge sufficiently to relieve the pressure indicated by the gauge for a period of 20 seconds and screw the gauge tightly into the tube again. Then place the tube in water at a temperature of 100 deg. fahr. (90 deg. fahr. November 1st to March 1st). The level of the water must be just below the lower edge of the pressure gauge. Stir the water continually and maintain the temperature exactly constant for ten minutes, then tap the gauge lightly with the finger and read the pressure.

*See Paragraph 1824, I. C. C. Regulations.

A correction of pressure figures should be made according to the initial temperature of the gasoline. This correction should be as follows:

For tests on samples taken at a temperature of 50 to 59 deg. fahr. inc.—deduct 1 lb.

For tests on samples taken at a temperature of 40 to 49 deg. fahr. inc.—deduct 2 lb.

For tests on samples taken at a temperature below 40 deg. fahr.—deduct 3 lb.

Although the regular inspectors of the Bureau of Explosives are available for making these tests when required, still, the responsibility for knowing the vapor pressure of the liquid shipped and that it is in proper containers, rests entirely on the shippers, who should provide facilities and require frequent tests to be made of their product, and should send a copy of the results of such tests to the Chief Inspector, Bureau of Explosives, 30 Vesey Street, New York City, for information and record.

In making reports, the gravity of the liquid, the temperature of liquid gas placed in test tube, the pressure at 70 deg. fahr. before venting tube, the corrected pressure at 100 deg. fahr. (90 deg. fahr. from November 1st to March 1st) after venting at 70 deg. fahr. should all be recorded.

Very respectfully, B. W. Dunn,
Chief Inspector.*

GASOLINE RULES

The following simple rules have been found approximately true for Sistersville casinghead gasoline and they are probably fairly accurate for Oklahoma and other casinghead gasolines. Neither the vapor tension rise nor the evaporation loss are regular, but vary more or less with the temperature:

*Bureau of Explosives, Office of the Chief Inspector, Underwood Building, 30 Vesey Street, New York City, November 27, 1916, (Revised), M. C. L. No. 147.

Vapor Tension Rule—1st—Vapor tension rises or falls about 0.28 pounds for each degree rise or fall of the boiling point.

2nd—64 deg. fahr. is approximate boiling point for 10 pound vapor tension liquid tested at 100 deg. fahr.

Example:—At what temperature will 7 pound vapor tension liquid boil in the cars? As the vapor tension will fall about 0.28 pounds per degree, a drop of 25 degrees will remove all pressure. Then the boiling point will be 75 deg. fahr. (or 25 degrees below 100) the point at which the vapor tension was seven pounds.

Evaporation Loss Rule—1st Natural gasoline loses about 3.5 per cent for the first ten degrees rise in temperature above its boiling point, and about 7 per cent for each 10 degrees thereafter.

Example:—A—What would we lose on raw gasoline received at 40 deg. fahr. and sent out at a temperature of 70 deg.?

The first ten deg. equals 3.5 per cent loss and the next 20 deg. 14 per cent, so the loss would be approximately 17.5 per cent altogether.

Heat Value of Oil or Gasoline—A method to determine the approximate B.t.u.'s per pound of oil,various gravities, is:

First—Set down constant, 18650.

Second—Deduct 10 from Baume Gravity; multiply this by 40, adding result to the constant; this will give B. t. u.'s in pound of oil of that gravity.

Example:

What is the heat value of 27 deg. Baume Fuel Oil?

$27—10=17\times40=680,$

add Constant $18650=19330.$

This gives 19330 as B. t. u.'s in one pound of oil 27 deg. Baume.

Multiply by pounds per gallon for various gravities, to get heat values per gallon. Example:

Table 114

Gravity Deg. B.	Wt. per Gallon	B. t. u. per lb.	B. t. u. per gal.	B. t. u. per bbl.
23	7.635	19170	146,363	6,147,000
24	7.585	19210	145,708	6,120,000
25	7.536	19250	145,068	6,093,000
26	7.490	19290	144,482	6,068,000

Note—The higher the gravity, the more B. t. u.'s per pound; but the HIGHER the gravity, the less pounds per gallon.

For comparison with coal, take B. t. u.'s per pound of coal, multiply by 2000 pounds, for B. t. u.'s per ton, and compare with B. t. u.'s per barrel.

Excellent Coal has about 14750 B. t. u.'s per pound.
Good Coal has about 12500 B. t. u.'s per pound.
Poor Coal has about 10000 B. t. u.'s per pound.

Table 115—HEAT VALUES OF THE LIGHTER HYDROCARBON PRODUCTS FROM CRUDE OIL

Commercial Term	Baume	B. t. u. per lb.	B. t. u. per Standard U. S. Gallon
Gasoline..............	100	22,250	....
	95	22,050	....
	90	21,850	115,805
	85	21,650	117,343
	80	21,450	119,476
	76	21,290	120,927
	75	21,250	121,337
	73	21,170	122,150
	70	21,050	123,142
	68	20,970	123,932
	65	20,850	125,100
	64	20,810	125,484
	62	20,730	126,453
	58	20,570	127,945
Kerosene:			
(Water White)......	48	20,170	132,516
	46	20,090	133,397
	44	20,010	134,467
	42	19,930	135,524
	40	19,850	136,369

A gallon of 65 deg. gasoline, which weighs 5.999 pounds, will produce 22.7 cubic feet of gas; and one gallon of 70 deg. gasoline, weighing 5.85 pounds, will produce 23.1 cubic feet of gas. Temperature 60 deg. fahr.

Gravity—The Bureau of Mines considers the gravity being taken as specific gravity. To conform to current practice the gravity of the product is conveniently taken by Baume Hydrometers. Hydrometers conforming to the U. S. Bureau of Standards specifications should be used without exception. Tagliabue Hydrometers, not based on the modulus 140, read too high. Tables in Part 19 are based on the U. S. Bureau of Standards specifications.

Table 116—DISTILLATION PRODUCTS OF CRUDE OIL—(*Burrell*)

Commercial Name of Product	Gravity deg. B.	Boiling Points deg. fahr.	Chemical Names
Straight casinghead gasoline before blending.....	75 to 105	up to 275	Chiefly Butanes, Pentanes and Hexanes.
Straight refinery Gasoline as sold to retail trade...	62.9	110 to 400	Chiefly Pentanes, Hexanes, Heptanes and Octanes.
Naphtha (a).............	50.0	302 to 428	Chiefly Octane, Nonane and Decane.
Kerosene................	45.9	356 to 616	Chiefly Decanes.

Expansion—For complete table applying to the expansion of gasoline and petroleum oils, see Table 3, Circular No. 57, Bureau of Standards. The commonly used coefficient of expansion of .0005 per degree when applied to oils of high Baume gravity is considerably in error.

AVIATION GASOLINE SPECIFICATIONS

Owing to the great height at which combats in the air now take place between the airplanes, in some cases as high as 22,000 feet, the matter of obtaining gasoline which will fire properly at the high altitude and consequent low temperature is a serious one. This problem received a great deal of attention from the authorities in Washington in conjunction with the oil refiners of the country. Originally the demand came for gasoline for aviation purposes with an end point of 302. An attempt was made to have this degree lowered, and a conference at Washington between the refiners and the Fuel Administration resulted in lowering the end point to 257 degrees for first quality gasoline. There was, of course, great difficulty in supplying a grade of gasoline in large quantities with such a low end point, but in view of the necessity, the refiners agreed that the difficulty could be overcome, and they made delivery of the required quantity by pro-rating among the refiners.

Experiments conducted by the Bureau of Mines and Bureau of Standards resulted in tentative specifications being drawn, which specifications for the respective purpose are given as follows:

Specifications for Aviation Gasoline (Export)

1. Color.

The color shall be water white.

Test: Inspection of a column in a standard 4 ounce oil-sample bottle.

2. Foreign Matter.

The gasoline shall be free from acid, undissolved water and suspended matter.

Acid Test: Shake ten cubic centimeters of gasoline with five cubic centimeters of pure water and test the water with blue litmus paper.

Water and suspended matter would be in evidence in the test for color.

3. Doctor Test.

The gasoline shall yield a negative doctor test.

Directions for making doctor test on gasoline:

(A) Preparation of reagents: Sodium Plumbite or "doctor" solution: Dissolve approximately 125 grams of Sodium Hydroxide (NaOH) in a liter of distilled water. Add 60 to 70 grams litharge (PbO) and shake vigorously for 15 to 30 minutes, or let stand with occasional shaking for at least a day. Allow to settle and decant or siphon off the clear liquid. Filtration through a mat of asbestos may be employed if the solution does not settle clear. The solution should be kept in a bottle tightly stoppered with a cork.

Sulphur: Obtain pure flowers of sulphur.

(B) Making of test:

Shake vigorously together two volumes of gasoline and one volume of the "doctor solution." (10 cc. of gasoline and 5 cc. of "doctor solution" in an ordinary test tube; or proportional quantities in a 4 ounce oil-sample bottle may conveniently be used). After shaking for about 15 seconds, a small pinch of flowers of sulphur should be added and the tube again shaken for 15 seconds and allowed to settle. The quantity of sulphur used should be such that practically all of the sulphur floats on the surface, separating the gasoline from the "doctor solution."

(C) Interpretation of results:

If the gasoline is discolored, or if the sulphur film is so dark that its yellow color is noticeably masked, the test shall be reported as Positive, and the gasoline condemned as "sour." If the liquid remains unchanged in color, and if the sulphur film is bright yellow or only slightly discolored with gray or flecked with black, the test shall be reported Negative and the gasoline considered "sweet."

4. Corrosion and Gumming Test.

The gasoline, when subjected to the corrosion test, shall show no black corrosion and no weighable amount of gum.

Directions for making test:

The apparatus used in this test consists of a freshly-polished hemispherical dish of spun copper, approximately 3½ inches in diameter.

Fill this dish within ⅜ inches of the top with gasoline to be examined and place the dish upon a steam bath. Leave the dish on the steam bath until all volatile portions have disappeared.

If the gasoline contains any dissolved elementary sulphur the bottom of the dish will be blackened.

If the gasoline contains undesirable gum-forming constituents there will be a weighable amount of gum deposited on the dish. Acid residues will show as gum in this test.

Interpretation of results:

Corrosion—It is specified that no black deposits shall be formed. This wording is intended to admit gasolines that have so small a quantity of sulphur that the deposit is only gray or peacock colored.

Gum—It is specified that there shall be no weighable amount of gum. The intention is to refuse admittance to gasolines that show an amount that can be readily weighed in this style of dish.

5. Volatility and Distillation Range.

When 5 per cent of the sample has been recovered in the graduated receiver, the thermometer shall not read more than 65 degrees Centigrade (149 degrees Fahrenheit), or less than 50 degrees Centigrade (122 degrees Fahrenheit).

When 50 per cent has been received in the receiver, the thermometer shall not read more than 95 degrees Centigrade (203 degrees Fahrenheit).

When 90 per cent has been recovered in the receiver, the thermometer shall not read more than 125 degrees Centigrade (257 degrees Fahrenheit).

When 96 per cent has been recovered in the receiver, the thermometer shall not read more than 150 degrees Centigrade (302 degrees Fahrenheit).

At least 96 per cent must be RECOVERED in the receiver from the distillation.

The DISTILLATION LOSS shall not exceed 2 per cent when the residue in the flask is cooled and added to the distillate in the receiver.

The distillation method and apparatus shall conform with those outlined and described in Bureau of Mines Technical Paper No. 166, entitled "Motor Gasoline Properties, Laboratory Methods of Testing, and Practical Specifications."

Specifications for Aviation Gasoline (Domestic).

1. Color.

The color shall be white.

2. Foreign Matter.

The gasoline shall be free from acid, undissolved water, and suspended matter.

3. Doctor Test.

The gasoline shall yield a negative doctor test.

4. Corrosion and Gumming Test.

The gasoline when subjected to the corrosion test, shall show no black corrosion and no weighable amount of gum.

Note: Methods for making tests for requirements Nos. 1, 2, 3 and 4, same as given in specifications for "Export" grade.

5. Volatility and Distillation Range.

When 5 per cent of the sample has been recovered in the graduated receiver, the thermometer shall not read more than 75 degrees cent. (167 deg. fahr.), or less than 50 deg. cent. (122 deg. fahr.)

When 50 per cent has been recovered in the receiver, the thermometer shall not read more than 105 deg. cent. (221 deg. fahr.)

When 90 per cent has been recovered in the receiver, the thermometer shall not read more than 155 deg. cent. (311 deg. fahr.)

When 96 per cent has been recovered in the receiver, the thermometer shall not read more than 175 deg. cent. (347 deg. fahr.)

At least 96 per cent must be recovered in the receiver from the distillation.

The distillation loss shall not exceed 2 per cent when the residue in the flask is cooled and added to the distillate in the receiver.

The distillation method and apparatus shall conform with those outlined and described in Bureau of Mines Technical Paper No. 166.

Specifications for Aviation Gasoline (Fighting)

1. Color.

The color shall be white.

2. Foreign Matter.

The gasoline shall be free from acid, undissolved water and suspended matter.

3. Doctor Test.

The gasoline shall yield a negative doctor test.

4. Corrosion and Gumming Test.

The gasoline, when subjected to the corrosion test, shall show no black corrosion and no weighable amount of gum.

Note: Methods for making tests for requirements Nos. 1, 2, 3 and 4, same as given in specifications for "Export" grade.

5. Volatility and Distillation Range.

When 5 per cent of the sample has been recovered in the graduated receiver, the thermometer shall not read more than 75 deg. cent. (167 deg. fahr.), or less than 60 deg. cent. (140 deg. fahr.)

When 50 per cent has been recovered in the receiver, the thermometer shall not read more than 95 deg. cent. (203 deg. fahr.)

When 90 per cent has been recovered in the receiver, the thermometer shall not read more than 113 deg. cent. (253 deg. fahr.)

When 96 per cent has been recovered in the receiver, the thermometer shall not read more than 125 deg. cent. (257 deg. fahr.)

At least 96 per cent must be recovered in the receiver from the distillation.

The distillation loss shall not exceed 2 per cent when the residue in the flask is cooled and added to the distillate in the receiver.

The distillation method and apparatus shall conform with those outlined and described in Bureau of Mines Technical Paper No. 166, entitled "Motor Gasoline, Properties, Laboratory Methods of Testing, and Practical Specifications." See pages 460 to 474.

PART FIFTEEN

Dangers of Casinghead Gas and Gasoline

DANGERS OF GASOLINE PLANTS — EXPLOSIVE MIXTURES — HAZARDS OF HANDLING GASOLINE — SAFETY RULES.

DANGERS OF GASOLINE PLANTS

Nearly all gas and oil men are familiar with the fact that gasoline vapors and some casinghead gas are heavier than air and flow or settle to the ground instead of rising or flowing upward as the lighter natural gas does. Yet, when the gas or oil men first started producing gasoline from casinghead gas on a large scale, they designed and built their compressor buildings along the same lines as natural gas compressor plants had been built for years, that is, ventilators were placed in the roof, but no ventilators were placed in the building near the ground, and in addition, concrete floors were invariably used.

Gasoline vapor is approximately three times heavier than air and the writer has known casinghead gas to have a gravity as high as 1.67.

The writer has visited many plants and has seen none but that some improvement could be made to improve the safety of the plant.

If gasoline plants were considered more in the same class with powder and high explosive plants and like precautions taken against accidents, no doubt there would be fewer explosions with less loss of life.

Some of the precautions taken at powder plants are as follows—Wood floors with no exposed nails; men wear shoes without nails in the soles or heels; no matches allowed to be carried on the person of any employee. Of course where

liquid explosives that create gases, are manufactured, ventilation both in the roof and near the ground are provided, or a forced ventilation or fan system is installed.

An example of a good combination to create an explosion is—heavy gas lying near the floor at the time of taking off a cylinder-head—men with shoes carrying nails in the heels—employee braces himself to loosen a nut and slips, causing a spark on the concrete floor. The survivors after the explosion do not know what caused the explosion.

In one gasoline plant which the author visited the yard surrounding the plant was graded with a fine chert. This might be the indirect cause of an explosion, for an employee wearing a shoe with a worn sole could very easily pick up a piece of this crushed stone. When he stepped into an improperly ventilated building and onto a concrete floor, he would instinctively scuff his feet until the piece of chert was removed. This friction would naturally cause a spark which might ignite the gas.

Very few plants are provided with lead hammers, but use the common steel hammer. A lead hammer is far the safest as one cannot strike a spark with it.

It would not be unreasonable to keep all steel hammers and cold chisels in the superintendent's office and to issue them only on permit, in which case the purpose for which they were to be used should be explained every time they were taken out.

While ventilators in the roof are a necessity, they should also be installed near the ground on at least two sides of the building. For this purpose the swinging type should be used, as they can be regulated according to the force and direction of the wind.

Concrete floors make the best foundation but they should be covered with some fibrous material such as linoleum.

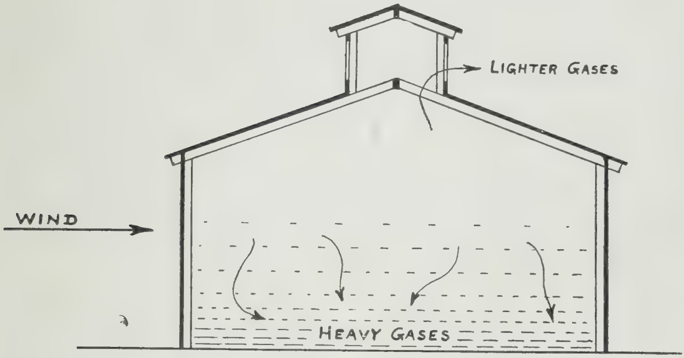


Fig. 139—DANGEROUS, DUE TO LACK OF VENTILATION

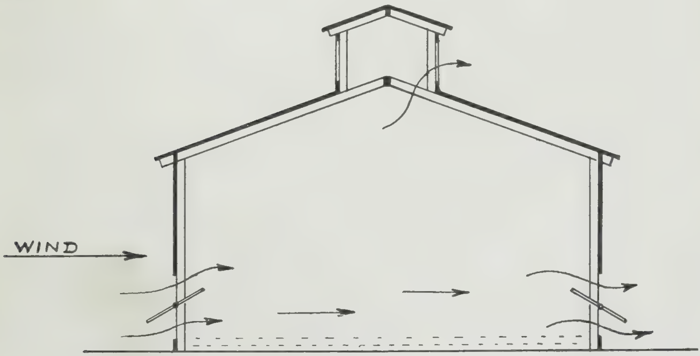


Fig. 140—PROPER VENTILATION, DANGER REDUCED TO MINIMUM

Three or four coats of floor paint will act in a similar manner, but it can hardly be said to be as safe as a fibrous floor covering.

Some plants build their gasoline storage tanks below the ground level in order to protect them from the heat of the sun, and pumps are installed in the pit, on a level with the bottom of the tanks. Naturally there is a little leakage of gasoline around the stuffing box of the pump plunger rod which constantly forms gasoline vapor in the pit. In such installations, when any repairs are needed, there is not only great liability of an explosion but the possibility of asphyxiation of the repair men.

Storage batteries should not be tested in any building or room in which there is liable to be gasoline vapor or casinghead gas.

In one or two instances attempts have been made to clean the coils by blowing compressed air through them resulting in explosions and the wrecking of a plant. The blowing of air through gasoline making coils invariably creates explosive mixtures and causes any pebbles or iron chips lying in the pipes to roll along the pipe and striking some obstruction are liable to make a spark thereby causing an explosion as in a gas engine cylinder.

High tension magneto and spark plugs are most commonly used. They should not be tested within any plant buildings.

Dangers of the Electric Flash Light—The pocket electric flash light while generally considered perfectly safe in gas is dangerous when the light is first equipped with a new battery, unless the light is turned on away from the gas zone and kept turned on while in the gas and till it is carried away from the gas.

The danger lies in releasing the button on the lights when equipped with a new strong battery at which time the act of releasing the button is liable to cause a make-and-break spark strong enough to cause an explosion.

To Extinguish Fires—The fire extinguisher is very effective in extinguishing small fires. It is good policy to have in an accessible location, a hand chemical cart holding at least twenty-five gallons. This size cart will extinguish a fire or blaze several feet in height.

Other methods employed are to have at various points around a plant, quantities of sand or salt. The sand and salt have a tendency to smother gasoline fires.

EXPLOSIVE MIXTURES*

The following table shows the small percentages of gases and vapors occurring in natural gas that are required to form explosive mixtures with air.

Table 117

Hydrocarbon	Gas in Mixtures of Gas and Air, Low Explosive Limit
	per cent
Methane	5.60 to 5.70
Ethane	3.00 to 3.20
Propane	2.15 to 2.30
Butane	1.60 to 1.70
Pentane	1.35 to 1.40

According to the above table, even if a natural gas consisted almost entirely of methane, as some natural gases do, an explosion would follow an ignition of a mixture of air and natural gas containing 5.50 per cent of methane.

HAZARDS OF HANDLING GASOLINE†

Detailed Precautions Concerning the Handling of Gasoline—(By George A. Burrell)—"No open light or flame of any kind, nor any machine or belt capable of producing a spark should be allowed in the room where the gasoline is being used. All shafting and machines with belts that are liable to cause a static electric spark should be well grounded.

*Burgess, M. J., and Wheeler, R. V. Tran. Chem. Soc. Vol. 99, 1911.
†From Technical Paper No. 127, Petroleum Technology No. 28, Bureau of Mines.

Table 118
EXPLOSIVE MIXTURES OF COMBUSTIBLE GASES*

Combustible Gas (Temperature 60 deg. to 65 deg. fahr.)	Lower Explosive Mixture	Upper Explosive Mixture
Air-gas (approximate)	15 00	50.00
Hydrogen	9.45	66.40
Water gas	12.40	66.75
Acetylene	3.35	52.30
Coal-gas	7.90	19.10
Ethylene	4.10	14.60
Methane	6.10	12.80
Benzine vapor	2.65	6.50
Pentane vapor	2.40	4.90
Benzoline vapor	2.40	4.90
Alcohol	8.00	12.00
Ethyl alcohol	4.00	13.60
Ether	2.00	8.00
Petrol	2.00	5.00

Only incandescent electric lights should be used, and these should be provided with guards to prevent their being smashed.

All electric switches, fuses, etc., should be outside the room.

Danger signs should be posted on all doors opening into the room, warning against the carrying of open lights of any kind inside.

Oily waste should at all times be placed in a safe receptacle to avoid the danger of spontaneous combustion. Oily waste will decay, smolder, and in time burst into flame. Sawdust when soaked with oil drippings will do the same thing, and its use should be forbidden. Sand is a safe material to use as an absorbent of oil.

A dangerous practice, common in many garages, is the cleaning of automobile parts with gasoline from an open can. Employees find it easy to clean grease and oil from the motor and other parts with a brush saturated with gasoline, and the gasoline is readily ignited by a spark. Such a spark may

* Petrol Air Gas by Henry O'Connor.

be caused by striking two pieces of metal together, by the ignition system on the automobile when the starting crank is turned, and in other ways. In one instance a nut that stuck was struck with a wrench, causing a spark. The car was instantly enveloped in flame.

When the use of an open pan is necessary the opening should be as small as possible and a cover should be provided. The cover should be put on whenever the pan is not in use.

Signs should be posted prohibiting an open flame near the place of storage or near a pump or other handling apparatus. The signs should explain the danger involved and give instructions for safe methods of operation.

Empty gasoline barrels should be stored with bungholes down, in safe places in the open air.

Rooms in which explosive or dangerous gases or vapors are used or generated should be safely inclosed, and should be provided with an improved system of ventilation.

Gasoline vapor is heavier than air, and a suction fan should be used to insure proper ventilation.

Table 119

VAPOR PER GALLON AND AIR REQUIRED FOR COMPLETE COMBUSTION

	Baume	Specific gravity	Vapor cubic feet per gal. at 32 deg. fahr. 14.7 atmos.	Proportion required for perfect combustion	
				Vapor	Air
				per cent	per cent
Pentane..	94	0.626	31.2	2.53	97.47
Hexane...	81	0.663	27.7	2.17	97.83
Heptane..	73	0.688	24.7	1.86	98.14
Octane...	65	0.719	22.6	1.64	98.36
Nonane..	59	0.741	20.8	1.47	98.53

Joints in tanks, pipes, conveyors, etc., used for storage of explosive liquids, gases, or vapors should be kept tight.

Before work is done on vessels, pipes, etc., sufficient time should be given to allow gas to escape.

Special care should be exercised before work requiring the use of heat or flame is done. Apparatus that has contained explosive gas should be filled with water or steam to force out the gas.

Extinguishing Burning Liquids—There are two principal methods of extinguishing burning liquids, as follows:

1. To form a blanket of gas or solid material over the burning liquid and cut off the air (oxygen) supply.

2. To dilute the burning liquid with a non-inflammable extinguishing agent that will mix with it.

Water may be used for extinguishing burning liquids, such as denatured alcohol, wood alcohol and acetone, that are miscible with it. If such a liquid as gasoline, which is not miscible with water, catches fire, the application of water produces little or no effect except to spread the burning liquid, and thus scatter the fire over a larger area. However, the application of a large quantity of water to a small quantity of burning oil, by its cooling effect, may aid in extinguishing the fire.

Of materials used to form a blanket of gas or solid material over burning liquid, thus cutting off the oxygen supply, several are in common use. These include sawdust, sand, carbon tetrachloride, and the so-called foam or frothy mixtures.

The efficiency of sawdust is due to its floating for a time on the liquid and excluding the oxygen of the air. Sawdust itself is not easily ignitible, and when it does ignite burns without flame. The character of the sawdust and its moisture content is of little or no importance. It may be well handled for extinguishing small fires, when just started, by means of long handled wooden shovels.

Sand probably serves about as well as sawdust for extinguishing fires on the ground, but is heavier and more awkward to handle. When thrown on a burning tank it sinks, whereas sawdust floats.

Carbon tetrachloride, the basis of various chemical fire extinguishers, if thrown on a fire forms a heavy non-inflammable vapor over the liquid, and mixes readily with oils, waxes, japan, etc. The vapor is about five times as heavy as air. Much of the carbon tetrachloride contains impurities that give it a bad odor, but when pure its specific gravity is 1.632 at 32 deg. fahr. When thrown on a fire, it produces black smoke, the hue of which is caused by unconsumed particles of carbon. Pungent gases are also produced probably hydrochloric acid gas and small volumes of chlorine gas. Although the fumes are pungent, brief exposure to them does not cause permanent injury.

The efficacy of carbon tetrachloride depends largely on the skill of the user. If liquid in a tank is on fire, the height of the liquid is important. When the liquid is low, the sides of the tank form a wall which retains the vapor, but when a tank is nearly full of highly volatile liquid like gasoline, only the most skilled operator can extinguish the fire.

For smothering some small fires of burning gasoline an ordinary blanket may be used.

Use of Foam or a Frothy Liquid Mixture as an Extinguisher—Installations embracing the use of foam or frothy liquid mixtures to extinguish fires in large gasoline storage tanks originated in Germany. For such an extinguisher two liquids are caused to mix in a tank, whereupon foam is produced. The tank is made air-tight and sufficiently strong to permit the foam to be forced out under pressure of a gas (carbon dioxide) simultaneously generated. The frothy mixture owes its efficacy to its blanketing action in excluding air (oxygen) from the fire. It is stiff and shrinks only slightly in volume even after half an hour. In one installa-

tion water, bicarbonate of soda, and soap bark are used in one tank, and acid in another tank. A fusible link, which will melt at 212 deg. fahr. releases a hammer, which breaks the glass tank containing the acid. The released acid is led through two perforated pipes into the solution, producing a violent ebullition of foam, which finds its way into the tank of burning oil.

In some large plants gasoline is continually stored under the pressure of non-inflammable gas, as nitrogen or carbon dioxide. In other plants it is stored in a tank, which is always kept filled, no air being admitted at any time. The tank may be filled with all gasoline or part gasoline and part water, water being pumped into the tank to force out the gasoline, when desired. The water may be drained off when more gasoline is to be added to the tank.

Relation of Properties of Gasoline and Gasoline Vapor to Inflammability—Some grades of gasoline, particularly the better grades used to drive automobiles, are much more hazardous to handle than are others. They mix with air in larger proportions and pass into the vapor form (evaporate) more rapidly, and hence more quickly render a given volume of air explosive than do the heavier grades, such as are used for cleaning purposes and for fuel in the engines of some motor trucks and other large internal-combustion engines.

Action of Gasoline Vapor in Air—Gasoline vapor mingles with air in the same manner that water vapor does. At any particular temperature a definite proportion of water vapor will be found in the atmosphere if it has become completely saturated, a condition that seldom exists. Usually a limited supply of water has been given off into the air, and the atmosphere is spoken of as having a certain relative humidity, meaning that the saturation is incomplete or that more water vapor could exist in the air were a source of moisture available. In a similar manner gasoline vapor mixes with air.

The amount of vapor carried will depend on the temperature of the air and the readiness with which the vapor can be obtained.

If gasoline is exposed to the air of a room and for a long enough time, the air will contain at a certain temperature a fixed proportion of gasoline vapor, differing for different grades of gasoline, that can not be exceeded. The author has worked out the values for four different grades. The results for a temperature of 17.5 deg. cent. (63.5 deg. fahr.) are shown in the following table:

Proportions of Different Grades of Gasoline Vapor that Air Will Carry at a Temperature of 17.5 deg. cent. (63.5 fahr.)

Grade of Gasoline	Proportion of Gasoline (Vapor per cent)
Cleaner's naptha	5.0
64 deg. Baume gasoline	11.0
69 deg. Baume gasoline	15.0
73 deg. Baume gasoline	28.0

It will be noticed that air will hold almost six times as much vapor from the lighter gasoline as from the heavier cleaner's naptha. If the lighter and better grades of gasoline are heated, their vapors, when a light is applied, also flash and burn at lower temperatures than do the heavier grades. This difference does not mean that some gasoline is a dangerous inflammable liquid and some is not. All grades are classed as highly inflammable and dangerous liquids.

Comparison of Inflammability of Gasoline and of Gasoline Vapor—If one takes the cover off a full pail of tightly inclosed gasoline and applies a match to the surface, the gasoline will flare up and burn as long as the gasoline lasts. On the other hand, if one puts a few drops of gasoline in a small tightly inclosed pail, waits a few minutes, and then introduces a flame or an electrical spark a violent explosion will most likely result. In the first case the vapor burns as fast as it comes from the gasoline, and mixes with the oxygen of the air. In the second case the oil vaporizes

in the pail and mixes uniformly with the air therein to form an explosive mixture and upon ignition explodes. Consequently, when one hears of a disastrous gasoline explosion one may be sure that the explosion resulted from the mixing of the vapor from the gasoline with air in the proportions necessary to form an explosive mixture.

One gallon of gasoline when entirely vaporized produces about 32 cubic feet of vapor. If a lighted match could be applied to pure gasoline vapor in the absence of air no fire or explosion would result. Gasoline liquid or vapor, like any other combustible material, needs the oxygen of the air in order to burn.

Explosive Range of Mixtures of Gasoline Vapor and Air—It is fortunate that gasoline vapor, like other gases and vapors, needs a certain proportion of air before an explosion can take place. The author found that in 100 parts by volume of air and gasoline, an explosion will not take place if there is less than 1.4 parts of gasoline vapor or more than 6 parts.* In other words, the explosive range is between 1.4 and about 6 per cent of vapor. Flashes of flame will appear in mixtures containing considerably smaller and larger proportions of vapor, and considerable pressure will be developed, but propagation through the mixture will not take place.

Although the range of explosibility mentioned is narrow as compared to that of many other mixtures of combustible gases and air, yet the proportion of gasoline vapor representing the lower limit is small, and indicates the great importance of not allowing even a little gasoline to be exposed in a room, because of the small quantity of vapor needed to make an explosive mixture with all the air in the room. If one gallon of gasoline is allowed to change completely into vapor simply by exposing it to the room air, and if the room is gas-tight, the one gallon can render explosive

* Burrell, G. A., and Boyd, H. T., Inflammability of mixtures of gasoline vapor and air; Technical Paper 115, Bureau of Mines 1015, pp. 10.

2,100 cubic feet of air, the amount contained in a room measuring 21 by 10 by 10 feet.

In the actual use of gasoline such conditions seldom exist. However, an assumed case may be that of a person filling an open pail from a larger tank or using gasoline for cleaning. When the pail is first filled with the gasoline, a small volume of pure gasoline vapor forms over the surface of the gasoline. Just above this layer of pure gasoline vapor is a mixture of vapor and air; at some point there will be an explosive proportion, and farther away from the pail there will be a small proportion of vapor, and finally still farther away no vapor at all, but pure air. However, all the time the user of the gasoline is at work, the vapor keeps forming, from both the gasoline in the pail and that applied to the object being cleaned, rendering more and more air inflammable or explosive, until finally there will exist a dangerous atmosphere that may completely surround him, so that a chance ignition will envelope him in flames and perhaps cause great damage to property. Ignition of the gasoline vapor may take place even some distance from the gasoline in a room adjoining the room in which the person works. As the gasoline evaporates, and more and more vapor is given off, it mixes with air farther and farther from the gasoline, and, if the evaporation lasts long enough, may travel to an adjoining room, where it may be ignited. On ignition a sharp flash will travel back through the adjoining room to the room where the gasoline is.

At ordinary temperatures air will hold about 5 to 28 per cent of gasoline vapor. As gasoline vapor is about three times as heavy as air, in a room containing a mixture of the vapor with air the vapor is found in largest proportion near the floor.

The limits of explosibility of mixtures of gasoline vapor and air are between 1.4 and 6 per cent of gasoline vapor, although dangerous flashes may be produced with mixtures,

containing less and more than these proportions. In other words, there is needed only a small proportion of gasoline vapor to render air explosive—1.4 cubic feet of the vapor to 97.5 cubic feet of air. One gallon of gasoline, can, under ideal conditions, render 2,100 cubic feet of air explosive.

A dangerous feature of gasoline vapor is that it may travel a considerable distance from the gasoline and there be ignited, the flash traveling back to the container of the liquid and causing a roaring fire in a few seconds."

GASOLINE DEPARTMENT—SAFETY RULES

For Gasoline and Vacuum Plants

1. Do not take chances. It is better to shut down a plant than to risk loss of life or property.

2. Any defects in buildings, machinery, stairs, ladders, walk-ways, etc., must be immediately reported to the person in charge of the plant.

3. When serious or dangerous defects occur in a machine, it must be shut down until repaired.

4. Never start an engine by tramping the flywheels Before turning an engine over render the ignition system inoperative by pulling out the retainer spring on the circuit breaker housing cap of the magneto.

5. Never stop an engine by pulling off or disconnecting the ignition wire; shut off the gas.

6. If necessary to shut down entire plant, in case of emergency, pull out lever of pressure regulator on engine fuel gas line.

7. If fire threatens compressor, accumulator, or meter building, close the valves on vacuum plant discharge, field and residue lines.

8. All employees must be familiar with the locations of fire fighting equipment, and the methods of using and charging the same. Fire plugs should be painted red so as to be easily identified.

9. Smoking or carrying matches inside the plant fence or buildings or around loading racks is prohibited.

10. Magnetos, spark plugs, and other ignition devices must not be tested, repaired or assembled in the compressor building or in any other building where gas or gasoline vapor might be present.

11. All electric lights in any room or building where gas or gasoline vapor might be present, should have vapor proof globes and must not be lighted unless the same are in place.

12. Electric light bulbs must not be removed from or placed in any circuit, either inside or outside of the building, while the current is on.

13. Extension lamps must not be used unless they have vapor proof globes, protected by metal guards, and metal covered cords. Electric flash lights must not be switched on or off in any place where inflammable gas or vapor might be present.

14. Waste and rags must be kept in the cans provided for the purpose, except when actually in use. Waste or rags must not be placed around machinery to catch drip oil, or hung up in any building to dry.

15. Do not use gasoline or naptha to clean machinery; use kerosene.

16. The engineer on tour is responsible for the boiler, and must see that the proper water level is maintained.

17. Before working on any moving part of a compressor vacuum pump or booster pump, see that the clutch is out, or, if there is no clutch, either block the engine fly wheels, or unlace the belt.

18. Tanks and tank cars must be free from gas and gasoline vapor before anyone enters them. If possible, steam them out. Men must not enter tanks or tank cars without having ropes attached to their bodies, and someone stationed on the outside to pull them out in case they should be overcome by gas.

19. None but company automobiles are permitted inside the plant fence or buildings.

20. No persons except officers and employees of this Company, and federal and state officials or inspectors, provided with properly signed and sealed identification cards, are permitted inside the plant, without permission from the general manager. In case of doubt, telephone the general manager's office before admitting anyone.

March 1st, 1918. .... General Manager.

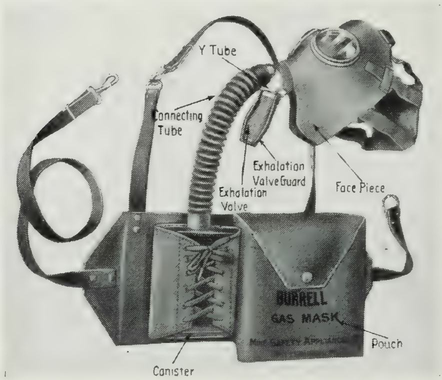


Fig. 141—GAS MASK WITH CANISTER

GAS MASKS

There are two types of Burrell gas masks for protection in tank work, namely the canister and the hose type.

The particular advantages of the Burrell mask in tank car work are as follows:

As the wearer of the mask has nothing in his mouth or on his nose he is able to breath normally under exertion; as the lens in the face piece doesn't fog up and there is nothing over the ears the wearer has clear vision and can hear plainly.

The mask being light in weight (approximately 4 pounds) the wearer can work practically unencumbered. The con-

sequence is that a man can work in tank cars where there are gasoline vapors for a considerable period of time, which he would be unable to do without protection against the fumes.

The canister type mask is used where there is a sufficient supply of oxygen. The hose type is used in places where the percentage of oxygen is too low to sustain life. As the hose on this type mask is extended out into the open air, a man works independent of the supply of oxygen in the tank. We have found from experiments that 50 feet of hose is the greatest length through which a man can breath without trouble. Beyond 50 feet the breathing resistance becomes too great for comfort.

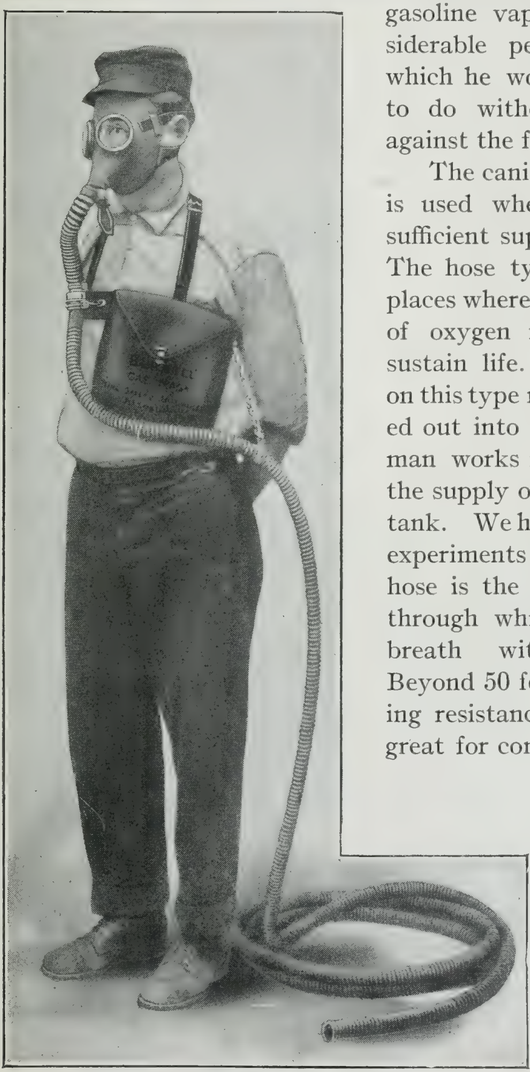


Fig. 142

Fig. 143

PART SIXTEEN

Transportation of Gasoline

GASOLINE DRUMS—TANK CARS—RAILROAD RATES AND RULES—I. C. C. REGULATIONS.

Gasoline Drums—Steel drums of the very best type manufactured should be used and must stand a pressure of forty pounds per square inch without any leaks whatever. A fifty-five gallon drum should weigh not less than seventy pounds without hoops and a one hundred and ten gallon drum should weigh not less than one hundred and thirty pounds without hoops.

If a drum, such as is used for shipping gasoline and high distillates, filled with 64 deg. Baume gasoline is allowed to stand in the sun with the thermometer registering 95 deg. fahr. with a pressure gauge attached, it will show that the heat has caused a gas pressure of twenty nine and one half pounds. For the purpose of transporting gasoline, special drums have been designed to withstand over eighty pounds pressure.

Do not use wooden plugs. Metal plugs should be close fitting, using a gasket of asbestos.

Glycerine drums are not satisfactory holders of gasoline. Drums should not be filled full, but only to within about two inches of the top, to allow for expansion. High gravity gasoline lies dormant when cold, but when its temperature rises above its boiling point it begins to agitate or boil, increasing the vapor tension in the tank or drum which raises the boiling point to that corresponding to the increased vapor pressure, thus maintaining a condition of equilibrium.

It is better to ship to a colder climate than to a warmer one. This lessens the liability for losses due to boiling from increased temperature.

Table 120—NORMAL DAILY TEMPERATURES

Parkersburg, W. Va.

U. S. Government Readings

	Jan	Feb	Mar	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	32	32	37	48	58	68	74	75	70	61	48	39
2	32	32	38	48	59	68	75	75	70	60	48	38
3	32	32	38	49	59	68	75	75	70	60	47	38
4	32	32	38	49	60	69	75	75	70	60	47	38
5	32	32	39	49	60	69	75	75	69	59	47	38
6	32	32	39	50	60	69	75	75	69	59	46	37
7	31	32	39	50	60	70	75	75	69	58	46	37
8	31	32	40	50	61	70	75	75	68	58	46	37
9	31	33	40	51	61	70	75	75	68	58	45	37
10	31	33	40	51	62	70	75	74	68	57	45	37
11	31	33	41	51	62	71	76	74	68	57	44	36
12	31	33	41	52	62	71	76	74	67	56	44	36
13	31	33	41	52	62	71	76	74	67	56	44	36
14	31	34	42	52	63	71	76	74	67	55	44	36
15	31	34	42	53	63	72	76	74	66	55	43	36
16	31	34	42	53	63	72	76	74	66	54	43	35
17	31	34	43	53	64	72	76	73	66	54	43	35
18	31	34	43	54	64	72	76	73	66	54	42	35
19	31	35	43	54	64	72	76	73	65	53	42	34
20	31	35	44	54	65	73	76	73	65	53	42	34
21	31	35	44	55	65	73	76	73	65	52	41	34
22	31	35	44	55	65	73	76	72	64	52	41	34
23	31	36	45	56	66	73	76	72	64	52	41	34
24	31	36	45	56	66	73	76	72	64	51	40	33
25	31	36	45	56	66	74	76	72	63	51	40	33
26	31	36	46	57	66	74	76	72	63	50	40	33
27	31	37	46	57	66	74	76	71	62	50	40	33
28	32	37	46	58	67	74	76	71	62	50	40	32
29	32	....	47	58	67	74	76	71	62	49	39	32
30	32	....	47	58	67	74	75	71	61	49	39	32
31	32	....	47	.....	68	.....	75	70	.....	49	.....	32

This table shows the temperatures to which gasoline shipped to W. Va. may be expected to be exposed, and to which gasoline shipped from W. Va. has probably been exposed.

Table 121—NORMAL DAILY TEMPERATURES

Oklahoma City, Okla.

U. S. Government Readings

	Jan	Feb	Mar	April	May	June	July	Aug.	Sept.	Oct.	Nov	Dec.
1	35	36	43	55	64	72	79	80	76	68	54	42
2	35	36	44	55	64	73	79	80	76	67	54	42
3	35	36	44	56	65	73	79	80	75	67	53	42
4	35	36	44	56	65	73	79	80	75	66	52	42
5	35	36	45	56	65	74	79	80	75	66	52	41
6	35	36	45	57	65	74	79	80	75	66	52	41
7	35	36	46	57	66	74	79	80	74	65	51	41
8	35	37	46	57	66	74	80	80	74	65	50	41
9	35	37	46	58	66	74	80	80	74	64	50	40
10	34	37	47	58	66	75	80	80	74	64	50	40
11	34	37	47	58	67	75	80	79	74	64	49	40
12	34	37	48	59	67	75	80	79	73	63	49	40
13	34	38	48	59	67	75	80	79	73	63	49	40
14	34	38	48	59	68	76	80	79	73	62	48	39
15	34	38	49	60	68	76	80	79	72	62	48	39
16	34	39	49	60	68	76	80	79	72	61	47	39
17	34	39	50	60	69	76	80	79	72	61	47	38
18	35	39	50	60	69	76	80	78	72	61	47	38
19	35	39	50	61	69	77	80	78	71	60	46	38
20	35	40	51	61	69	77	80	78	71	60	46	38
21	35	40	51	61	70	77	80	78	70	59	46	37
22	35	40	52	62	70	77	80	78	70	59	45	37
23	35	41	52	62	70	77	80	78	70	58	45	37
24	35	41	53	62	70	78	80	78	70	58	45	36
25	35	41	53	62	71	78	80	77	69	57	44	36
26	35	42	53	63	71	78	80	77	69	57	44	36
27	35	42	54	63	71	78	80	77	69	56	44	36
28	35	43	54	63	72	78	80	77	68	56	43	36
29	35	....	54	64	72	78	80	76	68	55	43	36
30	35	....	54	64	72	78	80	76	68	55	43	35
31	35	....	55	.....	72	78	80	76	.....	54	.....	35

This table shows the temperatures to which gasoline shipped to Oklahoma may be expected to be exposed, and to which gasoline shipped from Oklahoma has probably been exposed.

Table 122
PRESSURES GENERATED BY HEATING GASOLINE AND CONFINED LIQUEFIED NATURAL GAS*

Temperature		Pressures Generated by—			
		Refinery gasoline (80 deg. Baume)	Casinghead Gasoline Obtained at		
			50 pounds pressure	250 pounds pressure	400 pounds pressure
Deg. cent.	*Deg. fahr*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
0	32	0	..	107	360
5	41	0	9	117	375
10	50	0	12	130	398
15	59	0	16	144	423
20	68	3	20	154	453
25	77	5	25	175	482
30	86	10	30	193	510
35	95	16	34	210	545
40	104	26	40	231	585
45	113	41	46	251	630
50	122	92	52	275	690
55	131	150	58	...	755
60	140	..	65	...	...

TANK CARS

Tank cars of one kind and another have been used on American railroads for nearly forty years. Originally they were merely tubs or vats loaded on flat cars. Horizontal tanks came later and then followed the modern type of tank car.

Insulated Cars—This design of tank car has many advantages over the old common tank car. The great advantage is that the insulation surrounding the tank keeps the temperature of the contents from being affected by the atmospheric temperature. This permits shipping higher gravity gasoline with far less loss than with the old design car. As the liquid is kept at an even temperature, there is also less liability of the gasoline boiling on a hot day, causing

* By George A. Burrell.

Fig. 144—STORAGE TANKS

the safety valves to blow and allowing the gasoline and gas to escape into the atmosphere.

The inner tank is made of extra heavy material, tested and made perfectly tight at 100 lb. pressure. Over this, heavy paper is wrapped and secured to prevent the sweating of the tank. Then 2 inches of the best quality of insulating material is carefully applied with joints broken. Another layer of water-proof paper is wrapped around the insulation and over this another steel tank of lighter material is built. The tank heads and dome being similarly insulated. The tanks are designed to be unloaded either by gravity through the bottom outlet or by air pressure by pipes extending through the dome.

Tanks are anchored to the underframe without the use of head blocks.

False Domes—Some railroad companies require a false dome to be used on tank cars, with a vacuum line attached so as to carry off all gasoline vapors while loading. The vapors are piped to the gathering lines and are passed through the plant again.

This system in loading tank cars is especially necessary where a company is obliged to load cars on a railroad company's switch, alongside of the main line. It is also a very efficient method to employ in loading, as what was formerly wasted by the vapors escaping into the atmosphere would be saved.

When gasoline plants are located some distances from the loading switch and there are no gathering lines under vacuum nearby, it might prove impractical.

Gauge of Tanks—Multiply the square of the diameter of the tank by .7854; multiply the result by the length of the tank in inches, divide by 231 and the result is the capacity of the tank in U. S. gallons. If the tank has curved ends (as all car tanks have) add to the length two-thirds of the dish at each end.

Table 123—TANK CAR OUTAGE TABLE*

Temp. 60 Deg. Fahr. | Outage Expressed in Gallons

Inches	Capacity of Car							
	4231 gal.	6000 gal.	6641 gal.	7000 gal.	8087 gal.	8102 gal.	8505 gal.	10000 gal.
1/4	3	4	4	4	5	5	5	6
1/2	6	8	8	8	10	10	10	12
3/4	9	13	13	13	16	16	17	19
1	13	18	18	18	23	23	25	26
1 1/4	18	24	25	25	31	31	33	36
1 1/2	23	31	33	33	39	39	45	46
1 3/4	29	38	41	41	48	48	56	58
2	35	46	49	50	58	58	67	71
2 1/4	41	54	58	59	69	69	79	84
2 1/2	48	63	68	69	80	80	92	98
2 3/4	55	72	78	79	91	91	105	111
3	63	82	88	90	103	103	119	125
3 1/4	71	92	99	101	115	115	133	140
3 1/2	79	103	110	113	128	128	148	156
3 3/4	87	114	123	125	141	141	163	171
4	96	125	134	137	154	154	178	186
4 1/4	105	136	146	150	167	167	194	203
4 1/2	114	148	159	163	181	181	211	220
4 3/4	123	160	172	176	195	195	228	237
5	133	173	186	190	210	210	244	254

Prevention of Fires and Explosions from Blowing Safety Valves—Many disastrous fires and explosions have occurred indirectly and directly from blowing safety valves on tank cars filled with gasoline. Safety valves are set at 25 lb. When the pressure within the tank exceeds 25 lb. the safety valves "blow off" and permit the gasoline gas which generally is accompanied with a gasoline spray to flow into the atmosphere. The gas being heavier than air will follow the ground. Whenever a safety valve is blowing, the first thing to be done is to turn a stream of water on the car. This cools the shell and generally lessens the boiling, thus decreasing the pressure within. If it is not possible to use the stream of water, wet blankets can be thrown over the car and water thrown on the blankets from pails.

* Courtesy of Phoenix Refining Co.

Table 124—TANK CAR OUTAGE TABLE

Capacity of an 8,000 gallon Tank Car at Different Levels

Wet Reading ft.	in.	Contents U. S. gal.	Wet Reading ft.	in.	Contents U. S. gal.	Wet Reading ft.	in.	Contents U. S. gal.
	1	20	3	4	4160	*6	7	8084
	2	64	3	5	4293	6	8	8094
	3	102	3	6	4424	6	9	8104
	4	157	3	7	4554	6	10	8114
	5	218	3	8	4684	6	11	8124
	6	285	3	9	4814	7	0	8133
	7	357	3	10	4945	7	1	8143
	8	435	3	11	5073	7	2	8153
	9	517	4	0	5201	7	3	8163
	10	602	4	1	5330	7	4	8173
	11	692	4	2	5456	7	5	8183
1	0	786	4	3	5582	7	6	8193
1	1	881	4	4	5705	7	7	8203
1	2	981	4	5	5829	7	8	8213
1	3	1082	4	6	5950	7	9	8224
1	4	1187	4	7	6071	7	10	8235
1	5	1296	4	8	6191	7	11	8245
1	6	1405	4	9	6308	8	0	8255
1	7	1518	4	10	6424	8	1	8265
1	8	1630	4	11	6536	8	2	8275
1	9	1746	5	0	6649	8	3	8285
1	10	1863	5	1	6758	8	4	8295
1	11	1983	5	2	6867	8	5	8305
2	0	2104	5	3	6972	8	6	8314
2	1	2225	5	4	7073	8	7	8324
2	2	2349	5	5	7173	8	8	8334
2	3	2472	5	6	7269	8	9	8342
2	4	2598	5	7	7362	8	10	8347
2	5	2724	5	8	7452	8	11	8349
2	6	2853	5	9	7538	9	0	8352
2	7	2981	5	10	7620	9	1	8354
2	8	3109	5	11	7699	9	2	8357
2	9	3240	6	0	7771	9	3	8359
2	10	3370	6	1	7840	9	4	8361
2	11	3500	6	2	7903	9	5	8363
3	0	3630	6	3	7961	9	6	8363
3	1	3761	6	4	8003	9	7	8364
3	2	3894	6	5	8051	9	8	8365
3	3	4027	6	6	8074			

* Denotes top of tank shell (inside).

Loaded tank cars should always be set in shady spots if possible.

Insulated tank cars greatly lessen the liability of high temperatures even on hot days, which condition creates boiling.

Sealing—In shipping gasoline in tank cars, it is advisable to affix a wire seal or lock on the dome cover. It has been found that while loaded tank cars are enroute to destination, the dome cover is removed and considerable quantities of gasoline stolen. While the monetary loss may be considerable, the liability of an explosion from lighted lanterns endangering public safety and property is far greater.

Care of Tank Cars—The tank may wear on the head blocks, allowing tank to shift. This will become worse rapidly and may result in breaking off the outlet pipe. Wide solid oak shims should be carefully driven in between the head block and the steel head block plate whenever there is a space between the head block and the tank head.

The tank bands may become loose as the tank settles on the slabbing. They can easily be tightened up and this should be carefully looked after.

Safety valves will sometimes work loose from the elbow. Where vent valves are used they will sometimes work out. Keep them firmly screwed down.

Before loading a tank always examine the interior. Open the outlet valve and wipe it and the valve seat with a cloth or waste to remove any sediment that might prevent the valve closing tightly.

The valve rod is attached to the valve by a bolt and nut. The continual pounding and jarring may cause the bolt to break or the nut to come off. This should be carefully looked after and the bolt replaced as often as necessary. Otherwise you may have to pump out a tank because you cannot open the valve.

At the upper end of the valve rod of most tanks there is a strong spring to keep the valve shut. This spring works upon a collar which is secured to the valve rod by a set screw. All these parts should be inspected frequently to see that the nut and collar do not work loose or the force of the spring weaken. By means of the collar and set screw the spring may be tightened as much as desired.

Heater pipes are secured to the saddles by means of bars bolted down. Should the nuts work loose the coils may shift and break. Have the coils inspected each trip and the nuts tightened if necessary.

Always close the outlet valve before replacing cap on the discharge pipe. This is especially necessary in freezing weather, as otherwise the outlet extension pipe may fill up from the draining and freezing, break the pipe. In removing the cap for unloading in cold weather never strike the cap or nozzle with a hammer or steel bar.

When there is a stop cock on the outlet extension they are sometimes hard to open. Do not use too great force to open the cock as this is a severe strain on the outlet pipe. Loosen the nut on the opposite side of the cock and tap it with a mallet. This will enable you to open it easily.

Dome lids and outlet caps are frequently lost in transit on account of the failure of those unloading cars to see that these are properly secured to the car by chains and that they are firmly screwed down before the car goes out. This means delay and expense in replacing missing parts at the next loading place. Never allow a car to go out with the outlet cap hanging but always screw it and the dome lid into place.

RAILROAD RATES AND RULES

Demurrage Rules on Tank Cars—Railroads charge the customary demurrage on privately owned cars except when cars are on the private tracks of the car owners. This decision was made by the Interstate Commerce Commis-

sion Nov. 14, 1908. In connection with this ruling they also defined a "private track" as one "outside the carrier's right of way, and of which the railroad does not own the roadbed, rails, ties or right of way." The commission further decided on the same date that "a private car owned by one shipper and used with his consent by another shipper is not a 'private car,' as that phrase is defined by the commission in the matter of demurrage charges." This last restriction, however, does not apply in the case of cars owned by a car company and leased to a shipper.

Table 125—FREIGHT RATES PER GALLON OF OIL

Corresponding to Various Rates per 100 lb.

Rates expressed in Cents per Gallon

Cents per 100 lb.	Container		Cents per 100 lb.	Container	
	Bbl.	Tanks		Bbl.	Tanks
5	0.45	0.375	28	2.52	2.100
6	0.54	0.450	29	2.61	2.175
7	0.63	0.525	30	2.70	2.250
8	0.72	0.600	31	2.79	2.325
9	0.81	0.675	32	2.88	2.400
10	0.90	0.750	33	2.97	2.475
11	0.99	0.825	34	3.06	2.550
12	1.08	0.900	35	3.15	2.625
13	1.17	0.975	36	3.24	2.700
14	1.26	1.050	37	3.33	2.775
15	1.35	1.125	38	3.42	2.850
16	1.44	1.200	39	3.51	2.925
17	1.53	1.275	40	3.60	3.000
18	1.62	1.350	41	3.69	3.075
19	1.71	1.425	42	3.78	3.150
20	1.80	1.500	43	3.87	3.225
21	1.89	1.575	44	3.96	3.300
22	1.98	1.650	45	4.05	3.375
23	2.07	1.725	46	4.14	3.450
24	2.10	1.800	47	4.23	3.525
25	2.25	1.875	48	4.32	3.600
26	2.34	1.950	49	4.41	3.675
27	2.43	2.025	50	4.50	3.750

By the foregoing is meant that when a privately owned tank car is shipped to a customer, even though such customer owns his own switching tracks (ties, rails and roadbed) the railroad will charge demurrage for any time over the customary allowance. In other words whenever a privately owned tank car leaves the car owner's private track it is considered in service.

Mileage Rules of Railroads—Railroads allow one and one-half cents per mile run on both loaded and empty movements of tank cars. Private car owners are required to furnish printed postal cards to the railroads for reporting deliveries to connecting lines and for reporting mileage earnings.

Practically all railroads follow the rule of handling empty tank cars free, under orders of owners. Empty mileage must, however, be equalized by loaded mileage, or paid for later at tariff rates. The general rule is to furnish private car owners with a statement of their loaded and empty mileage once a year. The car owner is then allowed six months additional to equalize any excess empty mileage. If this is not done the railroad will collect for the excess empty mileage at tariff rate.

If the loaded mileage exceeds the empty mileage the balance is carried forward as a "credit" to the next period.

The rate charged by railroads for hauling empty tank cars varies, according to territory from ten cents per mile west of the Mississippi river to four cents per mile in Central and Eastern territory.

New, or newly acquired cars, moving empty from shops where built to owners, or from place of purchase, must be billed with freight charges to the owner or lessee.

Limit of Load—Under the rules formerly in force, the railroads allowed cars to be loaded according to the size of car journals, 10 per cent of overloading beyond the published limit being permitted. By a new rule adopted by the

Master Car Builders' Association and taking effect September 1st, 1909, the total weight of car and contents is taken into account. The rule prescribes the following "limit weights" for cars:

Table 126

Size Journals	Wheel Seat	Axle Center	Limit Weight of car and contents
5½ x 10 in.	6¾ in.	5⅞ in.	161,000
5 x 9	6¼	5 5/16	132,000
4¼ x 8	5⅝	4⅞	112,000

By this rule there is a decided advantage in using steel cars of improved design where all superfluous and useless dead weight is eliminated.

I. C. C. REGULATIONS*

1822 (*d*) Tank cars used for the shipment of dangerous articles other than explosives must comply with Master Car Builders' specifications, and a tank car that leaks or one that has any defect which would make leakage during transit probable or that has not been tested and stenciled in compliance with Master Car Builders' specifications must not be used for the shipment of any inflammable liquid.

(*e*) The tanks and their fittings must be examined by the shipper to see that they are in proper condition for loading. Tanks must be examined for evidence of previous leaks; safety and outlet valves, dome covers, and outlet-valve caps must be in proper condition before loading; tanks must be loaded with outlet valve caps off; after loading, tanks must not show any dropping of liquid contents at the seams or rivets, and should such dropping appear cars must be properly repaired by calking; outlet valves must not permit more

* From B. E. Pamphlet No. 9, I. C. C. Regulations, published by Bureau of Explosives, 30 Vesey St., New York, N. Y. Effective Sept. 1, 1918.

than a dropping of the liquid with valve caps off, otherwise valve must be reground and repaired. Dome covers and valve caps provided with suitable gaskets must be properly screwed in place before cars are tendered to the carrier.

(*g*) Tests of all tank cars and their safety valves, as made in compliance with Master Car Builders' specifications must be certified by the party making the tests to the owner of the tank car and to the chief inspector, Bureau of Explosives, and this certification must show the initials and number of the tank car, the service for which it is suitable, the date of test, place of test, and by whom made.

Inflammable Liquids—Red Label

1824. (*a*) All inflammable liquids must be shipped in packages complying with specifications that apply, as follows:

(*i*) In metal barrels or drums complying with Specification No. 5.

(*j*) In tank cars complying with Master Car Builders' specifications provided the vapor tension of the inflammable liquid corresponding to a temperature of 100 deg. fahr. does not exceed 10 pounds per square inch. A tank car must not be used for shipping inflammable liquids with flash point lower than 20 deg. fahr., unless it has been tested with cold-water pressure of 60 pounds per square inch and stenciled as required by Master Car Builders' specifications, and is equipped with safety valves set to operate at 25 pounds per square inch, and with mechanical arrangement for closing dome cover as specified in paragraph 1824 (*k*).

(*k*) Liquid condensates from natural gas or from casing-head gas of oil wells, made either by the compression or absorption process, alone or blended with other petroleum products, must be described as Liquefied Petroleum Gas when the vapor pressure[1] at 100 deg. fahr. (90 deg. fahr. November 1 to March 1) exceeds 10 pounds per square inch.

[1] In measuring the vapor pressure the container may be vented momentarily at a temperature of 70 deg. fahr.

When the liquid condensate alone or blended with other petroleum products has a vapor pressure not exceeding 10 pounds per square inch, it must be described and shipped as Gasoline, Casinghead Gasoline, or Casinghead Naphtha.

Liquefied petroleum gas of vapor pressure exceeding 10 pounds per square inch and not exceeding 15 pounds per square inch, from April 1 to October 1 and 20 pounds per square inch from October 1 to April 1, must be shipped in metal drums or barrels which comply with Shipping Container Specification No. 5; or in special insulated tank cars approved for this service by the Master Car Builders' Association.

Liquefied petroleum gas of vapor pressure exceeding 15 or 20 pounds per square inch as provided herein, and not exceeding 25 pounds per square inch, must be shipped only in metal drums or barrels which comply with Shipping Container Specification No. 5.

Liquefied petroleum gas of vapor pressure exceeding 25 pounds per square inch must be shipped in cylinders as prescribed for compressed gases (see pars. 1861 to 1863, inclusive).

When the liquid condensate, alone or blended with other petroleum products, has a vapor pressure not exceeding 10 pounds per square inch it must be described as Gasoline or Casinghead Gasoline or Casinghead Naphtha and must be shipped in metal drums or barrels complying with Specification No. 5; or in ordinary tank cars, 60 pounds test class equipped with mechanical arrangement for closing of dome covers as specified in Master Car Builders' specifications for tank cars.

Every tank car containing liquid condensates, either blended or unblended, including liquefied petroleum gas, as defined herein, must have safety valves set to operate at 25 pounds per square inch with a tolerance of 3 pounds above or below, and the mechanical arrangements for closing the dome

covers of such cars must either be such as to make it practically impossible to remove the dome cover while the interior of the car is subjected to pressure; or suitable vents that will be opened automatically by starting the operation of removing the dome cover must be provided.

The shipper must attach securely and conspicuously to the dome and dome cover three special white dome placards measuring 4x10 inches, bearing the wording as shown in Fig. 145.

10 Inches

CAUTION

AVOID ACCIDENTS

Do Not Remove This Dome Cover
While Gas Pressure Exists in Tank

KEEP LIGHTED LANTERNS AWAY

4 Inches

Fig. 145—TANK DOME COVER CAUTION LABEL

One placard must be attached to each side of the dome and one placard must be attached to the dome cover. The presence of these special dome placards must be noted on the shipping order by the shipper and by the carrier on the billing accompanying the car. Placards must conform to samples furnished by the Chief Inspector of the Bureau of Explosives.

1825. (*a*) Packages containing inflammable liquids must not be entirely filled. Sufficient interior space must be left vacant to prevent leakage or distortion of containers, due to increase of temperature during transit. In all such packages this vacant space must not be less than 2 per cent of the total capacity of the container. In tank cars the vacant

space must not be less than 2 per cent[1] of the total capacity of the tank, i. e., the shell and dome capacity, combined. If the dome of tank cars does not provide this 2 per cent, sufficient vacant space must be left in the shell of the tank to make up the difference.

Shipping Orders

1867. (*a*) Any article subject to these regulations whether label is required or not, must be described on the shipping order under the specific or general name provided for the description of such freight by the carrier's classification and tariff governing.

(*b*) The shipping order must also show opposite the entry of the article the color of label applied, or "No label required." For car load lots of such articles loaded by the shipper, the shipping order must show the kind of placard applied to the car, or "No placard required."

(*c*) The shipping order must also show the following certificate in the lower left-hand corner over the written or stamped facsimile signature of the shipper or of his duly authorized agent:

This is to certify that the above articles are properly described by name and are packed and marked and are in proper condition for transportation according to the regulations prescribed by the Interstate Commerce Commission.

[1] An outage of 2 per cent is frequently insufficient for light petroleum products, owing to the fact that they expand more than heavier petroleum products when the temperature increases, and this rate of expansion varies with the specific gravity of the material. It is recommended that when tank cars are loaded with gasoline, casinghead gasoline, or casinghead naphtha (see Par. 1824 (k)) the outage in tank shall not be less than the following:

Temperature of product when loaded	Minimum outage required when gravity is—		
	50-60° B.	60-70° B.	70-80° B.
	Per Cent	Per Cent	Per Cent
0– 60° F.	3.2	3.5	4.1
61– 70° F.	2.5	2.8	3.3
71– 80° F.	2.0	2.1	2.4
81–100° F.	2.0	2.0	2.0

Placards and Handling Cars

1901. Carriers must keep on hand an adequate supply of placards. Placards will be furnished by carriers to shippers for attachment to cars loaded by them.

1903. (*a*) When the lading requiring the placard is removed from cars, placards must be removed, except that "INFLAMMABLE" placards must remain on tank cars moved as "empty" until such cars are known to have been properly cleaned with steam or reloaded with a substance that does not require the placard. As provided in paragraph 1941 (b) acid placards which are painted or stenciled on tank cars may be allowed to remain.

(*c*) Outlet valve caps and dome covers must be securely placed in proper position on empty tank cars requiring "INFLAMMABLE" placards when offered for movement or when transferred to or from connecting lines in interchange.

1912. In unloading tank cars the following rules should be observed:

(*a*) The dome cover should be unscrewed by placing a bar between the dome-cover lug and the knob; the valve-rod handle in the dome should be moved back and forth a few times to ascertain if the valve is properly seated, and if seated, the valve cap should then be removed with a suitable wrench, having a pail to catch any liquid that may be in the valve nozzle.

(*b*) The unloading connection should be securely attached to the valve nozzle, and valve should then be raised by working the valve-rod handle. The dome cover should be placed over the dome opening, resting on a piece of wood, to allow air to enter the tank. The dome cover should not be replaced while unloading, as this action may result in collapse of the tank. After tank is unloaded the valve should be seated, valve cap and dome cover replaced. "INFLAMMABLE" placards must not be removed.

(*c*) When necessary to unload tank cars from the dome, or when necessary to transfer the contents of one tank car through the outlet valve into the dome of another tank car, care should be observed to see that all of the connections are tight and that the pipe or hose, when inserted into the open manhole for pumping or filling purposes, is surrounded by wet burlap to prevent the escape of vapors and to avoid igniting them.

(*d*) When the "blowing" of safety valves of a car containing inflammable liquids is noted, any available means for cooling the car shell and contents, such as spraying with water, should be utilized; and if practicable the car should be moved to an isolated point, to minimize the fire risk. Covering the safety valves with wet cloth, wet blankets, or wet gunny sacks will decrease the danger of igniting vapors escaping from a "blowing" valve. The burning of these vapors at the safety valve is not liable to cause an explosion. The valves are designed to permit, in emergencies, the burning in this way of the entire contents of the car.

Inflammable Placard

1913. A placard of diamond shape, printed on strong, thin, white paper for pasting on tank cars, and on strong tag board for tacking to wooden cars or to wooden boards of suitable size attached for this purpose to metal box cars or tank cars, measuring 10¾ inches on each side, and bearing in red and black letters the following inscription, must be securely attached to each outside end and to each side door of a box or stock car containing one or more packages protected by the red or the yellow diamond label, and to each side and end of a tank car containing an inflammable liquid:

NOTE—Cars containing cylinders of compressed non-inflammable gases (green label) do not require placards.

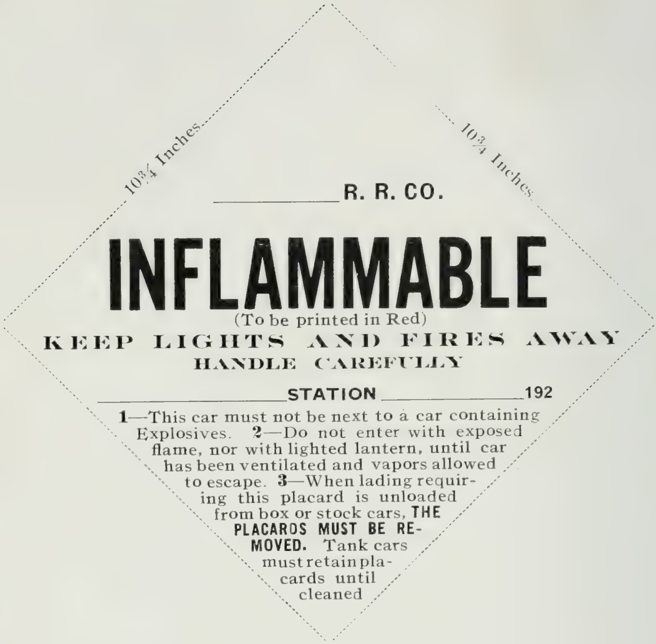


Fig. 146—INFLAMMABLE PLACARD, REDUCED SIZE

Shipping Container Specification No. 5

1. Iron or steel barrels or drums purchased hereafter and used for the shipment of inflammable liquids or acids as prescribed by I. C. C. Regulations must comply with the following specifications. Such barrels or drums purchased between March 31, 1912, and the effective date of these specifications must comply with the specifications effective March 31, 1912, or with these specifications.

In the interpretation of the minimum thickness of metal allowed for any specified gauge, a variation, due to commercial conditions of manufacture, of not more than 2½ per

cent below the specified standard will be considered satisfactory, provided the average weight per square foot is not less than the standard weight for the gauge specified. The standard weights referred to are as follows:

3.125	lb. per sq. foot for No. 14 gauge.
2.5	lb. per sq. foot for No. 16 gauge.
2.0	lb. per sq. foot for No. 18 gauge.
1.5	lb. per sq. foot for No. 20 gauge.

2. It is recommended that, when nature of contents will permit, each such container should be coated on the inside and outside in such manner and with such material as will prevent corrosion.

3. An iron or steel barrel or drum with a nominal capacity of over 55 gallons but not over 110 gallons must be constructed of metal the minimum thickness of which in any part of the completed barrel or drum must not be less than full No. 14 gauge, United States standard.

The weight of a barrel or drum with a nominal capacity of 100 to 110 gallons must be not less than 130 pounds in the black exclusive of the rolling hoops.

4. An iron or steel barrel or drum with a nominal capacity of over 35 gallons but not over 55 gallons must be constructed of metal the minimum thickness of which in any part of the completed barrel or drum must not be less than full No. 16 gauge, United States standard.

The weight of a barrel or drum with a nominal capacity of 50 to 55 gallons must be not less than 70 pounds in the black exclusive of the rolling hoops.

5. An iron or steel barrel or drum with a nominal capacity of over 10 gallons but not over 35 gallons must have a minimum thickness of metal in any part of the completed barrel or drum of not less than full No. 18 gauge, United States standard.

6. An iron or steel barrel or drum with a nominal capacity of not more than 10 gallons must have a minimum thickness of metal in any part of the completed barrel or drum of not less than full No. 20 gauge, United States standard.

7. Each barrel or drum must be tested under water or with all seams covered with soapsuds or heavy oil, by interior compressed air at a pressure of not less than 15 pounds per square inch sustained for not less than two minutes, and must stand this test without leaking.

8. The type of barrel or drum must be capable of standing without leaking a hydrostatic test pressure of not less than 40 pounds per square inch, sustained for not less than 5 minutes.

9. When filled with water to 98 per cent of its capacity the type of barrel or drum must also be capable of standing without leakage a test by dropping it diagonally on its chime from a height of 4 feet upon a solid concrete foundation.

10. Factory tests of the type package must be made with sufficient frequency to insure that the product complies with paragraphs 8 and 9.

11. Provision must be made for closing the bungholes and other openings in such manner as to prevent leakage. Bungs or other closing devices projecting beyond the chime or rolling hoops must be capable of withstanding the same test drop as prescribed by paragraph 9. Threaded metal plugs must be close fitting and threads in the reinforcements and on the plugs must be cut at right angles to the faced surfaces thereof to insure a uniform and solid bearing throughout the entire circumference of the gasket. Gaskets must be made of lead, fiber, leather, or other suitable material. Wooden bungs must be compressed, tapered bungs, and must be covered with a suitable coating and have a driving fit into a smooth bung hole tapered the same as the bung.

12. The method of manufacturing the barrel or drum and the materials used must be well adapted to producing a uniform product. Leaks caused by defective manufacture of a barrel or drum must not be stopped by soldering, but must be repaired by the method used in constructing the barrel or drum.

13. The name or initials of the manufacturing company or an identifying mark, a copy of which shall be filed with the Chief Inspector of the Bureau of Explosives, 30 Vesey Street, New York, must be plainly and permanently marked on each barrel or drum.

14. Each barrel and drum must be plainly and permanently marked with the words "COMPLIES WITH I. C. C. SPEC'N No. 5," or, if desired, this marking may be indicated by a symbol as follows:

I. C. C.—5

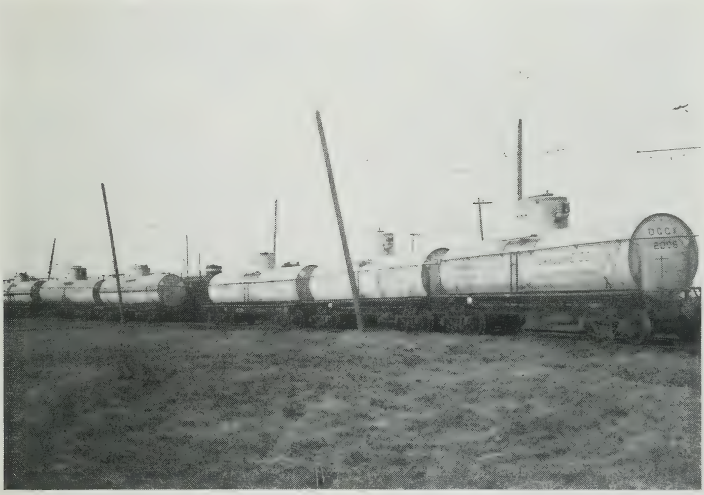


Fig. 147

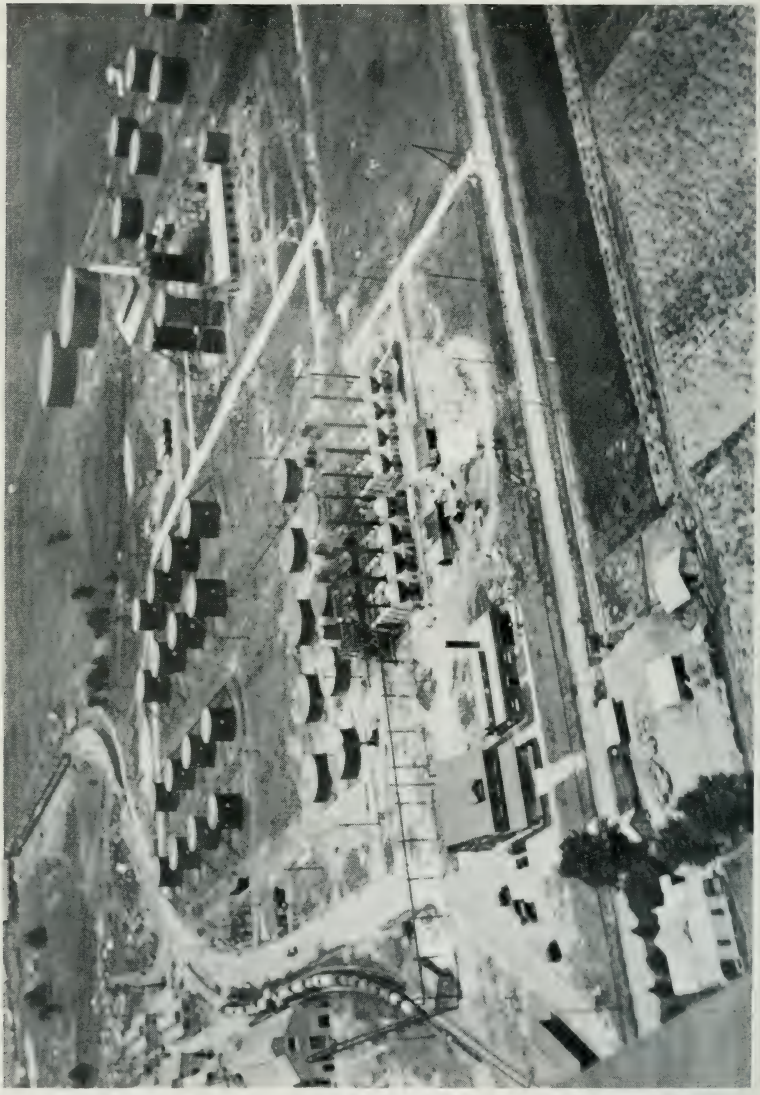


Fig. 148—AEROPLANE VIEW OF A REFINERY

PART SEVENTEEN

GASOLINE MARKET AND PRICES

Market—The main market for gasoline is for internal combustion engines such as automobiles, traction, motor boat, factory and small farm engines. While no doubt the automobile is the greatest consumer, even the little farm engine is a factor in its use of gasoline.

In 1905 automobiles consumed close to 30,000,000 gallons, while in 1921 it is estimated that the consumption of gasoline will be approximately 4,350,000,000 gallons, or 87,000,000 barrels, or over 145 times that of 1905.

While the automobile shows the greatest increase, all other types of internal combustion engines for various purposes have shown a most wonderful growth in numbers and have greatly increased the demand for gasoline.

When it is taken into consideration that one automobile consumes 500 gallons of gasoline in a year, we can gain a faint idea of the fast increasing demand for gasoline even with a big allowance for old cars being abandoned.

The annual increase of automobiles each year alone will cause an increased demand for gasoline of 12,000,000 barrels over the amount used in the previous year.

In 1920 there were manufactured 2,241,000 automobiles and trucks, and in 1916—1,617,688, automobiles and trucks This shows an increase in production in 1920 of 39 per cent over the number produced in 1916.

In 1920 there were 8,500,000 automobiles and trucks registered in the United States and in 1916 there were 3,544,952. This shows an increase in the number of cars in use in 1920 of approximately 140 per cent over 1916.

While the war greatly increased the demand for gasoline, no figures on the increased use are available.

GASOLINE DEMAND INCREASES

The comsumption of gasoline in the United States during the first half of 1921 was larger by 259,313,353 gallons, or a daily average of 710,447 gallons, than that of the corresponding period of 1920. Total consumption was 2,300,115,990 gallons compared with 2,142,705,363 gallons in the first six months of 1920. Production was larger than the previous year by approximately 18 per cent, but in spite of the enormous demand, prices of gasoline have declined in all sections of the country. The decline, however, is attributed solely to the lower cost of crude oil as it is contended that until recently there has been little or no reduction in the cost of refining, while transportation charges are at the same level as they were at the peak of 1920.

Reductions in gasoline prices on the average amount to 31 per cent, taking the leading cities of the United States as a whole. The average price at the close of August, 1921, was 20.2 cents compared with 29.3 cents a gallon on Jan. 1, 1921. The drop, in all, amounted to 9.1 cents. The largest declines since the beginning of the year have been at Dallas, Texas, and Denver, Col., where they amounted to 13 cents a gallon in each city. The lowest wholesale price was 15 cents a gallon at Kansas City, Mo., while the highest was 25.5 cents in Boston.

An analysis of the statistics issued by the United States Bureau of Mines shows that the production of gasoline for the first half of 1921 was 2,573,543,547 gallons, or 18 per cent larger than the production in the same period of 1920. The imports of gasoline, virtually all from Mexico, for the six months were 14,835,056 gallons, or 32 per cent less than those for the first six months of 1920. Exports amounted to 286,564,512 gallons, which were substantially less than the shipments in the corresponding period of 1920, while shipments to our insular possessions increased 45 per cent.

The following table gives the wholesale prices on Sept. 1, 1921, compared with those on Jan. 1 of previous years:

Table 127

	Sept. 1 1921	Jan. 1 1921	Jan. 1 1920	Jan. 1 1915
Atlanta, Ga.	21.0	31.0	26.0	10.5
Baltimore, Md.	21.0	29.5	28.5	9.0
Birmingham, Ala.	20.0	31.0	27.5	10.5
Boston, Mass.	25.5	32.0	25.5	14.0
Butte, Mont.	23.5	33.5	25.5	13.5
Chicago, Ill.	17.0	27.0	24.0	11.0
Cincinnati, O.	20.0	30.0	25.0	12.0
Cleveland, O.	20.0	30.0	25.0	12.0
Dallas, Tex.	18.0	31.0	26.0	11.0
Denver, Col.	19.0	32.0	25.0	13.0
Des Moines, Ia.	19.5	28.5	24.0	9.5
Detroit, Mich.	17.9	28.8	24.5	10.5
Houston, Tex.	18.0	29.0	26.0	11.0
Indianapolis, Ind.	18.6	28.3	25.5	11.0
Kansas City, Mo.	15.0	26.5	23.4	10.3
Louisville, Ky.	23.0	28.5	26.5	11.5
Memphis, Tenn.	22.0	30.0	25.0	12.5
Milwaukee, Wis.	19.3	27.9	24.1	11.0
Minneapolis, Minn.	19.2	28.2	25.0	11.0
New Orleans, La.	19.5	28.5	22.5	10.5
New York, N. Y.	24.0	31.0	24.5	12.0
Omaha, Neb.	18.5	29.5	24.0	11.5
Philadelphia, Pa.	21.0	31.0	25.2	10.0
St. Louis, Mo.	16.2	26.2	23.5	10.1
St. Paul, Minn.	21.2	28.2	25.0	11.0
San Francisco, Cal.	23.0	27.0	21.5	10.5
Seattle, Wash.	*25.0	28.0	22.5	11.5
Tulsa, Okla.	17.0	28.0	23.0	9.5
Vicksburg, Miss.	21.0	28.0	25.0	11.0
Wilmington, Del.	21.0	31.0	25.3	12.0

* Includes 1 cent State tax on a gallon.

Total stocks of gasoline in storage on June 30, 1921, amounted to 750,644,450 gallons, or 49 per cent larger than the total on June 30, 1920, and 62 per cent larger than on Jan. 1, 1921. Gasoline consumption is on the decline, however, June production having amounted to 14,344,813 gallons daily, a reduction of 125,118 gallons a day compared with May, but an increase of 1,004,522 gallons over the daily rate for 1920.

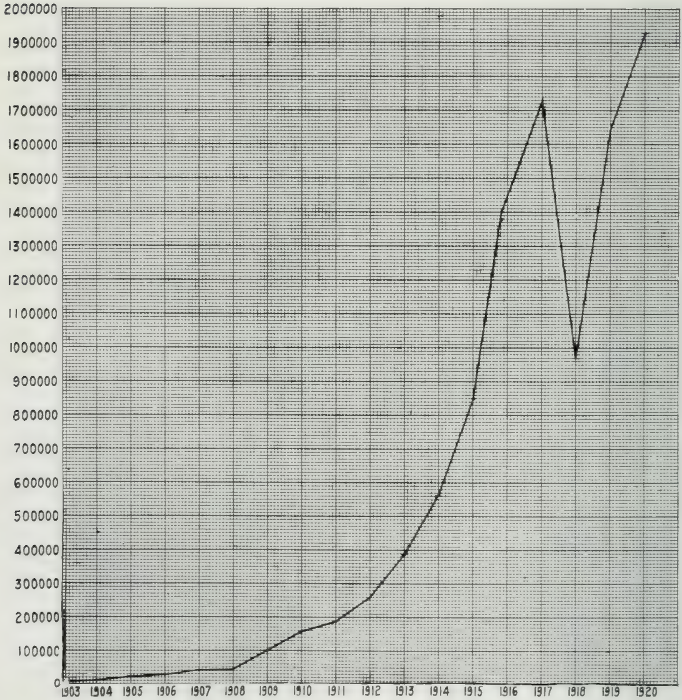


Fig. 149—CHART SHOWING PRODUCTION OF AUTOMOBILES IN U. S. FROM 1903 TO 1920

THE AUTOMOBILE INDUSTRY DURING 1920*

Automobiles registered in U. S. (approx.)	8,500,000
Passenger cars registered in U. S.	7,600,000
Motor trucks registered in U. S.	900,000
Cars and trucks owned by farmers	2,500,000
Percent of registration in towns of 5,000 population or less	55%
Percent of registration in towns of 1,000 population or less	33%
Percent of 1920 output bought by agricultural districts	60%
Passenger cars owned by doctors	110,000
State-owned cars and trucks	30,125
Municipally-owned cars and trucks	10,314
Cars and trucks entering and leaving New York City daily	154,725
Persons carried to and from New York daily by car and truck	420,095
Trucks owned by farmers	80,000
Labor-saving value of truck to each farmer annually	$150
Saving in transport charges to each farmer annually through use of truck	$240

AUTOMOBILE'S PART IN NATION'S BUSINESS

Amount of special taxes paid annually by industry to Federal Government	$257,000,000
Registration fees paid by car users	$81,000,000
Percent of all cars used more or less for business	90%
Percent of total mileage used for business	60%
Gain business efficiency from use of car as reported by average owner	57%
Average increase in doctors efficiency through use of car	104%

* By Alfred Reeves, General Manager National Automobile Chamber of Commerce.

Percent of steel supply used by automobile industry	4%
Amount paid by industry to railroads for freight on shipments of finished motor vehicles	$100,000,000

PRODUCTION IN 1920

Cars and trucks produced	2,241,000
Passenger cars produced	1,906,000
Motor trucks produced	335,000
Wholesale value of cars and trucks produced	$2,136,183,676
Wholesale value of passenger cars produced	$1,703,437,213
Wholesale value of motor trucks produced	$432,746,463
Average wholesale price of passenger cars produced	$897
Average wholesale price of motor trucks produced	$1273
Motor truck manufacturers in production	170
Passenger car manufacturers in production	90
States in which factories are located	32
Employees engaged in car and truck manufacture	300,000
Automobile tires manufactured	32,400,000
Increase in gasoline production over 1919	19%

AUTOMOBILE EXPORTS IN 1920

Value of motor vehicles and parts exported, including engines and tires	$338,000,000
Number of passenger automobiles exported	153,000
Increase in number of passenger cars exported	120%
Value of passenger cars exported	$155,000,000
Number of motor trucks exported	27,000
Increase in number of trucks exported	60%
Value of motor trucks exported	$45,000,000
Number of countries to which automobiles were exported during year	114

PART EIGHTEEN

Oil Notes

Table 128—WORLD'S PRODUCTION OF PETROLEUM IN 1919

(Compiled by G. B. Richardson, U. S. Geological Survey)

Country	Barrels of 42 U. S. gallons.	Metric tons	Cubic meters	Percentage of total by volume
United States	*a* 377,719,000	52,099,000	60,051,000	69
Mexico	*b* 87,073,000	*b* 12,964,000	*b* 13,843,000	16
Russia *c*	25,498,000	*d* 3,477,000	4,053,000	5
Dutch East Indies	15,428,000	*e* 2,143,000	2,453,000	3
India	*f* 8,735,000	1,164,000	1,388,000	2
Rumania	6,614,000	*g* 920,000	1,051,000	1
Persia	6,412,000	*h* 875,000	1,019,000	1
Poland (Galicia)	6,054,000	*i* 829,000	963,000	1
Peru	2,616,000	*j* 349,000	416,000	2
Japan	*k* 2,175,000	290,000	346,000	
Trinidad	*m* 1,841,000	256,000	293,000	
Egypt	1,501,100	*n* 231,100	239,000	
Argentina	1,183,000	172,000	*p* 188,000	
Venezula	425,000	*q* 65,000	68,000	
Alsace	344,000	*r* 47,000	55,000	
Canada	*s* 241,000	32,000	38,000	
Germany	234,000	*t* 33,000	37,000	
Italy	35,000	*u* 4,850	5,500	
Algeria	5,000	*v* 800	800	
England	*w* 1,900	250	300	
Other countries *x*	750,000	110,000	119,000	
	544,885,000	76,062,000	86,626,600	100

a Preliminary figures. Metric tons based on specific gravity of 0.8837.
b Boletin del Petroleo, September, 1920.
c Petroleum Times (London), June 12, 1920, credits Russia with 34,284,000 barrels.
d Oil News (London), Dec. 4, 1920. Barrels based on specific gravity of 0.859.
e Bureau of Mines, Dutch East Indies. Barrels based on specific gravity of 0.8761.
f Reported in Imperial gallons by Geological Survey of India. Metric tons based on specific gravity of 0.8403.
g Moniteur du petrole roumain, Feb. 15, 1920. Barrels based on specific gravity of 0.8766.
h Reported by American consul-general at London, Jan. 21, 1921. Barrels based on specific gravity of 0.86.
i Legation of Poland. Barrels based on specific gravity of 0.86.
j Informaciones y memorias de la Sociedad de ingenieros del Peru. Barrels based on specific gravity of 0.8403.
k Preliminary figures reported in koku by Oriental Economist Year book. Metric tons based on specific gravity of 0.8403.
m Reported in Imperial gallons by Trinidad Dept. Mines. Metric tons based on specific gravity of 0.8766.
n Reported by American consul-general at London, Jan. 21, 1921. Barrels based on specific gravity of 0.97.

p Comodoro Rivadavia oil fields. Report to Minister of Agriculture. Metric tons based on specific gravity of 0.9174.

q Boletin del Ministerio de fomento, vol. 1, No. 1, Oct. 1920. Barrels based on specific gravity of 0.959.

r Bulletin Soc. de l'industrie minerale, 5th ser., vol. 17, p. 141. Barrels based on specific gravity of 0.89.

s Preliminary report Canada Dept. Mines. Metric tons based on specific gravity of 0.8403.

t Private statistics through Consular Office, State Dept., Jan. 23, 1921. Barrels based on specific gravity of 0.89.

u Economista d'Italia. Nov. 9, 1920. Quoted by Economic Review, Dec. 3, 1920. Barrels based on specific gravity of 0.876.

v Algerian Bureau of Mines. Quoted in Commerce Repts., June 24, 1920. Barrels based on specific gravity of 0.98.

w Reported by American consul-general at London, Jan. 21, 1920. Figures furnished by H. M. Petroleum Executive. Metric tons based on specific gravity of 0.828.

x Estimated.

SUMMARY OF CRUDE PETROLEUM STATISTICS, 1909-1920

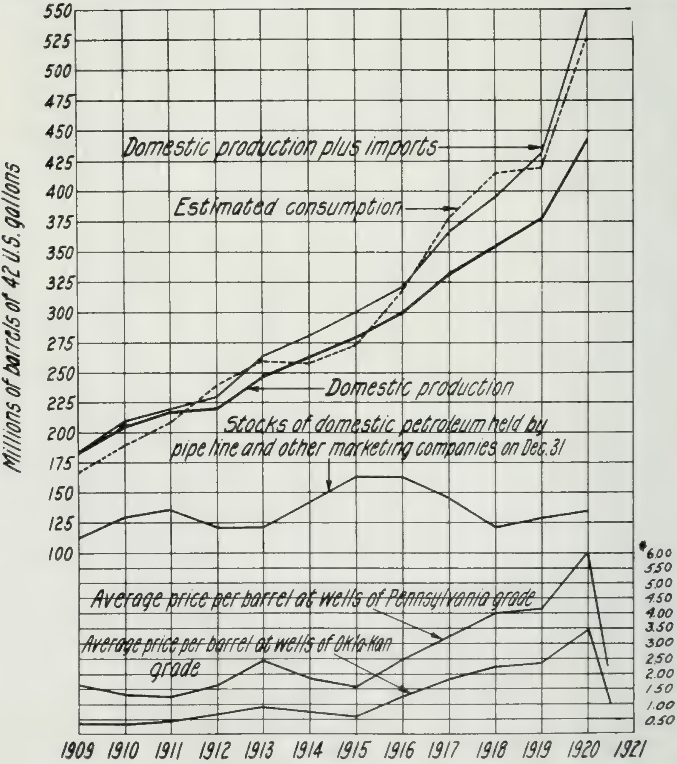


Fig. 150

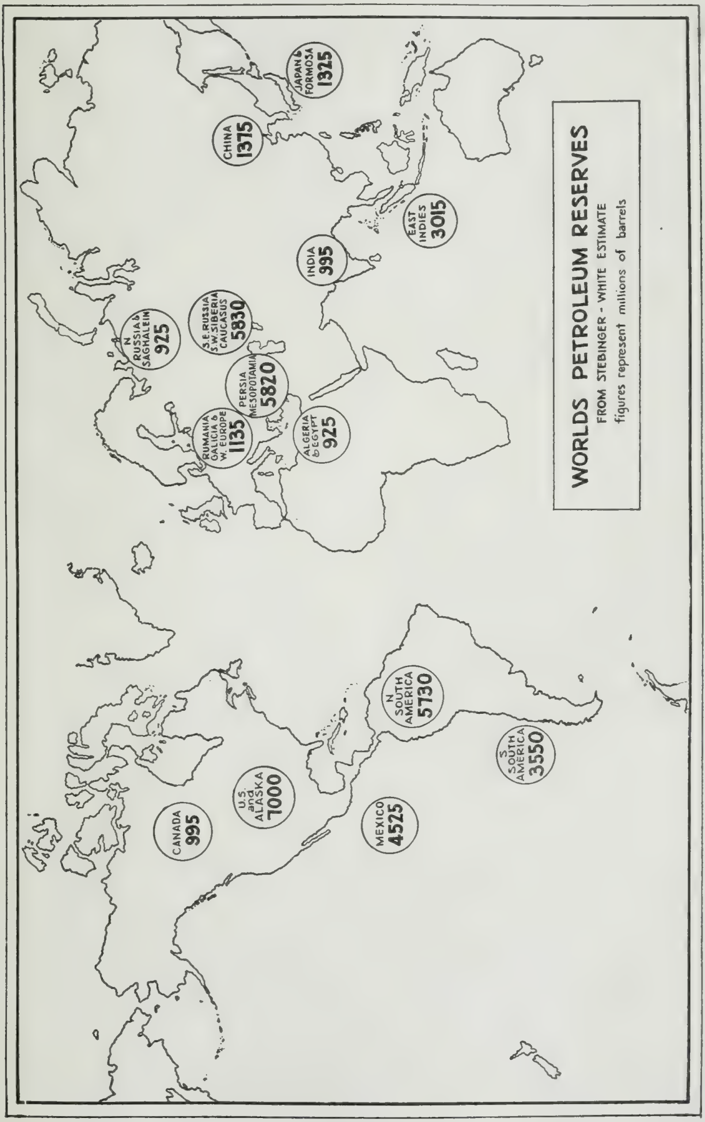

WORLDS PETROLEUM RESERVES
FROM STEBINGER - WHITE ESTIMATE
figures represent millions of barrels
CANADA 995
U.S. and ALASKA 7000
MEXICO 4525
N SOUTH AMERICA 5730
S SOUTH AMERICA 3550
N RUSSIA & SAGHALEIN 925
S.E. RUSSIA S.W. SIBERIA CAUCASUS 5830
PERSIA MESOPOTAMIA 5820
RUMANIA GALICIA & W. EUROPE 1135
ALGERIA & EGYPT 925
INDIA 995
CHINA 1375
JAPAN & FORMOSA 1325
EAST INDIES 3015

Fig. 151

Table 129—CONDENSED SUMMARY FOR JANUARY-OCTOBER, 1921, AND FOR OCTOBER, 1920

Month	Domestic production of petroleum			Imports of "mineral crude oil."		Exports of crude oil		Stocks *		Estimated consumption of domestic and imported petroleum.		Number of producing oil wells completed during month †
	Total (thousands of barrels)	Daily average (barrels)	Estimated value at wells	Total (thousands of barrels)	Daily average (barrels)	Total (thousands of barrels)	Daily average (barrels)	Held on last day of month (thousands of barrels)	Number of days' supply based on daily rate of consumption	Total (thousands of barrels)	Daily average (barrels)	
1921, Jan.	37,853	1,221,064	$111,000,000	13,193	425,577	736	23,730	124,256	79.8	48,268	1,557,032	1,832
Feb.	35,348	1,262,428	68,100,000	11,384	406,580	769	27,468	130,884	93.2	39,335	1,404,821	1,574
Mar.	40,965	1,321,452	72,800,000	12,303	396,875	728	23,492	138,181	94.7	45,243	1,459,452	1,452
Apr.	40,061	1,335,367	70,900,000	10,044	334,797	743	24,763	145,016	102.3	42,527	1,417,567	1,224
May	42,043	1,356,226	66,200,000	9,147	295,078	865	27,914	153,814	114.8	41,527	1,339,581	1,401
June	40,412	1,347,067	52,300,000	10,205	340,175	586	19,538	161,048	112.9	42,797	1,426,567	1,471
July	40,328	1,300,904	45,400,000	8,047	259,567	538	17,353	167,352	124.9	41,533	1,339,774	1,157
Aug.	40,966	1,321,484	43,900,000	3,352	108,136	884	26,542	168,190	122.4	42,596	1,374,065	952
Sept.	36,615	1,220,500	39,600,000	9,139	304,615	881	29,352	171,361	123.3	41,702	1,390,067	781
Oct.	35,638	1,149,613	51,551,000	11,576	373,400	747	24,085	172,245	117.1	45,583	1,470,419	752
1920, Oct.	39,592	1,277,161	123,800,000	11,361	366,498	749	24,177	116,403	74.9	48,174	1,554,000	2,086

* Net pipe-line and tank-farm stocks east of California and gross pipe-line, tank-farm, and producers' stocks in California plus stocks of Mexican petroleum held in the United States by importers.

† From Oil and Gas Journal and Standard Oil Bulletin (California).

STATISTICS OF PETROLEUM FOR OCTOBER, 1921 AND PRECEDING MONTHS

SUMMARY

Production of petroleum in the United States, according to the U. S. Geological Survey, continued to decrease during October. The daily average for the month, 1,149,613 barrels, was 70,887 barrels a day less than the production for September and was the smallest for any month since February, 1920. California, as a result of the strike in the oil fields, dropped to third rank, and decreased daily average production is also reported for all the other States with the exception of Wyoming, Illinois, and Montana, where small gains are recorded. Only 752 producing oil wells are reported to have been completed during October as compared with 2,086 wells in October a year ago.

This falling off in domestic production was offset by an increase in imports of Mexican petroleum, amounting to a daily average of 373,400 barrels.

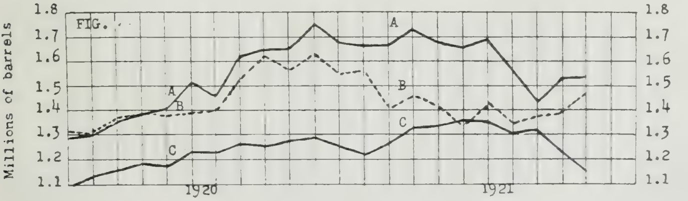


Fig. 152

Fig. 152.—Monthly fluctuations in average daily rate of—

(A) Domestic production of petroleum plus imports of mineral crude oil.

(B) Estimated consumption of domestic and imported petroleum.

(C) Domestic production of petroleum.

Consumption also increased by 180,352 barrels a day and was the greatest for any month of the year since January.

There was a net increase of stocks at the end of October, amounting to 884,000 barrels. An increase of 2,029,000 barrels of Mexican petroleum held in the United States by importers is contrasted with a decrease of stocks of domestic crude oil amounting to 1,145,000 barrels, which marks the first net decrease in pipe-line and tank-farm stocks east of California since April, 1920.

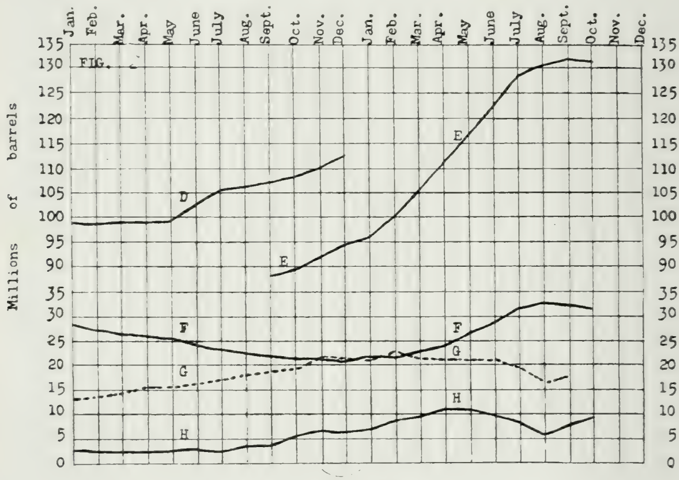


Fig. 153

Fig. 153.—Monthly fluctuations in stocks of petroleum held on last day of month—

(D) Stocks of domestic petroleum held by pipe-line and other marketing companies east of California as reported during 1920.

(E) Net pipe-line and tank-farm stocks of domestic petroleum east of California.

(F) Gross pipe-line, tank-farm, and producers' stocks in California.

(G) Refinery stocks of crude oil reported by Bureau ot Mines.

(H) Stocks of Mexican petroleum held in the United States by importers.

PRODUCTION OF OIL*

"Oklahoma was the largest oil producing state in 1920, with an output of 105,725,000 barrels, compared with 103,-300,000 barrels in 1918, a gain of 2 per cent. California was close behind, with a total production of 105,668,000 barrels, against 97,500,000 in 1918, an increase of 7 per cent.

Two of the large producing states increased output from 1918 to 1920 more than 100 per cent. Texas output in 1920 was 96,000,000 barrels, compared with 38,700,000 in 1918, an increase of 140 per cent, the largest gains shown by a single state. Louisiana production was 35,649,000 barrels, against 16,000,000, an increase of 120 per cent.

Kentucky output in 1920 of 8,680,000 barrels was an increase of 97 per cent over 1918 production. Every state increased its oil production in the two-year period except Kansas and Illinois.

The following table shows crude oil production by states in 1920, compared with 1918 (U. S. Geological Survey figures, in barrels) ·

Table 130

	1920	1918	Change		
Oklahoma	105,725,000	103,300,000	Inc.	2,425,000	2%
California	105,668,000	97,500,000	Inc.	7,168,000	7%
Texas	96,000,000	38,700,000	Inc.	57,300,000	140%
Kansas	38,501,000	45,400,000	Dec.	6,899,000	14%
Louisiana	35,649,000	16,000,000	Inc.	19,649,000	120%
Wyoming	17,071,000	12,600,000	Inc.	4,371,000	34%
Illinois	10,772,000	13,300,000	Dec.	2,528,000	20%
Kentucky	8,680,000	4,400,000	Inc.	4,280,000	97%
W. Virginia	8,173,000	7,800,000	Inc.	373,000	4%
Pennsylvania	7,454,000	7,400,000	Inc.	54,000	.006%
Ohio	7,412,000	7,300,000	Inc.	112,000	.001%
Indiana	932,000	870,000	Inc.	62,000	7%
New York	906,000	800,000	Inc.	106,000	13%
Montana	336,000	----------		----------	-------
Colorado	110,000	140,000	Dec.	30,000	21%
Other states	12,700	410,000	Dec.	397,300	96%
Total	443,402,000	355,920,000	Inc.	87,482,000	25%

* Courtesy of Wall Street Journal.

Central and north Texas production in 1920 amounted to 70,952,000 barrels and Texas Gulf Coast output 25,048,000 barrels. Principal increase in Texas output in the two years was in the north and north central districts, in 1919 by the discovery of Burkburnett and Ranger, and in 1920 principally through the development of Stephens County.

North Louisiana production in 1920 amounted to 33,896,000 barrels, while the coastal district of the state yielded only 1,753,000 barrels.

Domestic crude oil delivered to refineries increased from 380,000,000 barrles in 1918 to 433,000,000 barrels in 1920, or 14 per cent and exports of crude and refined oil from 64,000,000 barrels to 71,000,000 barrels, or 10 per cent. Mexican oil imports in the same time have increased from 53,000,000 barrels in 1918 to 106,000,000 barrels in 1920, or 100 per cent. Domestic refineries have increased their output of refined products from 1,040,000 barrels daily to 1,440,000 barrels daily, or 40 per cent.

Production of the four principal products increased as follows: Gasoline, from 10,400,000 gallons daily to 15,000,000 gallons daily, or 44 per cent; kerosene, from 5,600,000 to 7,100,000 gallons daily, or 26 per cent, gas and fuel oil from 20,100,000 to 27,400,000 gallons daily, or 31 per cent, and lubricating oil from 2,500,000 to 3,000,000 gallons daily, or 20 per cent.

At the end of 1920 refining capacity of the country was approximately 1,700,000 barrels daily against 1,100,000 barrels in 1918, a gain of about 600,000 barrels, or 55 per cent. Present capacity is sufficient to take care of the combined crude oil production of the United States and Mexico at the daily average rate in 1920 which was 1,694,000 barrels.

The following table gives a comparison of the position of the oil industry in 1918 and 1920, with change:

Table 131

Daily average, November:

	1920	1918	Gain	P.C.
Refinery consumption of crude oil including Mex. bbl.	1,440,000	1,040,000	400,000	40
Gasol output, gal.	15,000,000	10,400,000	4,600,000	44
Kerosene, gal.	7,100,000	5,600,000	1,500,000	26
Gas and fuel, gal.	27,400,000	20,100,000	6,300,000	31
Lubricatg oil, gal.	3,000,000	2,500,000	500,000	20
Annual total:				
Domestic crude output, bbl.	443,000,000	355,000,000	88,000,000	25
Imports Mexican oil, bbl.	106,000,000	53,000,000	53,000,000	100
Domestic consumption crude oil, bbl.	433,000,000	380,000,000	53,000,000	14
Exports, crude and refined, bbl.	71,000,000	64,000,000	7,000,000	10
Refining capacity, bbl. daily	1,698,000	1,100,000	598,000	55
Stocks crude oil, December 31	133,000,000	121,000,000	12,000,000	10

Fig. 154—TRACTION USED FOR PIPE LINE WORK

MEXICAN OIL COMPETITION

The question frequently arises as to how the shipments of Mexican petroleum into this country affect the market for domestic crudes.

An analysis of the figures for 1920, the record year for imports from Mexico, leads to the conclusion that prices received by the producer in the United States were controlled to a slight degree, if at all, by the receipts of Mexican crude.

The relative position of the domestic crude and Mexican oil imported is shown in the following table:

Table 132

Year	Shipments of Mexican Oil to U. S.	Domestic Production
1918	40,796,000 barrels	356,000,000 barrels
1919	57,808,000 barrels	378,000,000 barrels
1920	111,639,000 barrels	443,000,000 barrels

In 1918, the Mexican shipments constitued 10.2 per cent. of the total domestic and imported oil handled in this country; in 1919, 13.2 per cent.; in 1920, 20.1 per cent.

If all grades of crude were substantially the same, the receipt of a barrel of Mexican petroleum for every four barrels produced in the United States last year would undoubtedly have had an important bearing on the price of the domestic crude. However, the Mexican article is of a much inferior variety, from the refiners' standpoint, so much so that about 80 per cent. of it is suitable for fuel only. By comparison with higher grade oils, Mexican crude is not really refinable, because of its large content of coke. The lighter Mexican oil yields less than 20 per cent. of naphtha and refined oil which must be taken off to render the remainder suitable for fuel oil.

So if we examine the use to which the 111,639,000 barrels of Mexican imports of light and heavy crude combined were put last year we find that only 10,385,000 barrels were sold as gasoline; 3,851,000 barrels as refined oil or kerosene; and the remaining 97,403,000 barrels as fuel oil or asphalt. In other words, while the Mexican crude shipments were approximately 25 per cent of the total United States production, the gasoline from Mexican imports constituted but 9 per cent. of the 111,395,924 barrels of gasoline produced in this country last year from domestic crude.

Nor did the large quantity of imported fuel oil appreciably affect the sale of the domestic article. The market for fuel oil has been so low as to make sales at the Atlantic or Gulf seaboard unprofitable for mid-continent crude and the Atlantic seaboard was not a profitable market even for Gulf coast fuel oil.

Freight rates determine largely the market to which fuel or bunker oil goes. Mid-continent fuel oil could not be sold at New York, for instance, if there were no Mexican supply, for the freight charge of $2.50 a barrel makes the cost prohibitive. Fuel oil has been selling in this market at $1.35 a barrel in competition with coal. The great bulk of the Mexican fuel oil was delivered to the Atlantic coast largely for bunkering purposes and there displaced coal rather than American fuel oils. The 3,851,000 barrels of refined oil were primarily of an export quality and did not enter into competition with kerosene sold in the United States.

Of the gasoline produced in this country in 1920, 101,385,025 barrels were consumed at home and 371,152 barrels added to stocks. The remaining 15,639,747 barrels were exported. As for kerosene, Mexico's 3,851,000 barrels constituted 17 per cent. of the 55,240,344 barrels produced in this country. Of this total 33,395,611 barrels were consumed at home and 1,255,958 barrels added to domestic stocks, leaving 20,588,775 barrels for export.

So long as Mexico produces a large quantity of oil it is of course certain that this oil will find its way to market. The United States might protect its domestic producers from this competition in so far as the market in the United States is concerned, but could not extend any degree of protection for the exporters of United States petroleum products. As has already been shown the refined products of Mexican petroleum have entered into competition in this country with products from domestic crudes only to a very small extent.

If a prohibitive tax were to be imposed to keep foreign crudes out of this market the immediate result would be the expansion of refining facilities either on the Mexican seaboard or in European countries, and the loss of large sums by American industry due to the corresponding reduction in refinery activities here. With or without an import duty, Mexican fuel oil and refined oil will compete with American petroleum products in foreign countries.

Fig. 154—HAULING COMPRESSOR TO PLANT LOCATION

Table 133—SUMMARY OF CRUDE PETROLEUM STATISTICS, 1909-1920 *

Year	Domestic production *a*		Imports of mineral crude oil *b*		Estimated consumption *c*		Stocks of domestic petroleum *d*	
	Thousands of barrels	Per cent of yearly increase	Thousands of barrels	Per cent of yearly increase	Thousands of barrels	Per cent of yearly increase	Thousands of barrels	Per cent of yearly increase
1909	183,171	. .	70	. . .	167,089	. .	116,687	. . . .
1010	209,557	14	557	696	191,483	15	131,030	+12
1911	220,449	5	1,710	207	211,150	10	137,233	+ 5
1912	222,935	1	7,383	332	240,188	14	122,870	−10
1913	248,446	11	17,809	141	261,692	9	122,803	. . . .
1914	265,763	7	17,247	3	261,293	. .	141,550	+15
1915	281,104	6	18,140	5	273,271	5	163,755	+16
1916	300,767	7	20,570	13	318,599	17	162,397	− 1
1917	335,316	12	30,163	47	377,736	19	146,042	−10
1918	355,928	6	37,736	25	413,078	9	121,727	−17
1919*e*	377,719	6	52,822	40	418,477	1	127,867	+ 5
1920*e*	443,402	17	106,175	101	531,186	27	133,690	+ 5

a 1909–1918, inclusive—Petroleum removed from producing properties plus oil consumed for fuel on the leases. 1919-1920—Preliminary figures. Petroleum removed from producing properties.
b From records of Bureau of Foreign and Domestic Commerce.
c Sum of domestic and net imports plus decrease of stocks or minus increase of stocks.
d Held by pipe line and other marketing companies on December 31 of each year.
e Preliminary figures.

Table 134—AVERAGE PRICE PER BARREL AT WELLS, 1909-1920

Grade	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
Pennsylvania	$1.65	$1.34	$1.30	$1.60	$2.46	$1.89	$1.56	$2.51	$3.25	$3.97	$4.13	$5.96
Oklahoma-Kansas	.38	.38	.47	.67	.94	.76	.60	1.26	1.81	2.20	2.29	3.41

* Prepared by G. B. Richardson, Bureau of Mines.

Table 135

PRODUCING OIL WELLS IN THE UNITED STATES, OCTOBER 31, 1920

State	Approximate number of producing oil wells.	Approximate production per well per day.
California*....................	9,490	32.3 bbl.
Colorado....................	70	4.1
Illinois....................	16,800	1.7
Indiana....................	2,400	1.1
Kansas....................	15,700	7.4
Kentucky....................	7,800	3.2
Louisiana:		
Northern....................	2,560	31.7
Coastal....................	140	34.6
Total Louisiana........	2,700	31.8
New York....................	14,040	0.2
Ohio:		
Central and Eastern........	18,500	0.8
Northwestern..............	21,100	0.3
Total Ohio.............	39,600	0.5
Oklahoma....................	50,700	6.0
Pennsylvania................	67,700	0.3
Texas:		
Central and Northern......	9,400	22.9
Coastal....................	1,700	49.7
Total Texas............	11,100	27.0
West Virginia..............	19,500	1.1
Wyoming and Montana.......	1,000	55.9
Total..................	258,600	4.98

* Reported by the Standard Oil Company and the Independent Producers' Agency.

WELLS

The following well data for the States east of California are based on information supplied to the United States Geological Survey by pipe-line companies. The data are

only approximate, because a few pipe-line companies do not maintain lists of wells with which their lines are connected, and the data for these companies have been estimated on the basis of production per well per day. However, it has been necessary to estimate less than 10 per cent of the total number of wells. A canvass is being made of producers whose wells are connected with the pipe lines of those companies that can not now report concerning wells. It is expected that in the not distant future more complete information will be available and at that time well data will be recorded by districts.

The following table shows the high and low extremes of Pennsylvania crude oil prices from its first production in 1860 to the present time:

Table 136

PRICES OF PENNSYLVANIA CRUDE OIL FROM 1860-1920

Year	Highest	Lowest
1860	\$20.00	\$2.00
1861	1.75	.10
1862	2.00	.10
1863	4.00	2.00
1864	14.00	3.75
1865	10.00	4.00
1866	5.00	1.65
1867	4.00	1.50
1868	5.50	1.80
1869	7.00	4.25
1870	4.90	2.75
1871	5.15	3.40
1872	4.10	3.00
1873	3.05	1.00
1874	1.90	.45
1875	1.65	.90
1876	4.23⅛	1.48¾
1877	3.70	1.53¾
1878	1.87½	.78¾
1879	1.28¾	.63⅛

PRICES OF PENNSYLVANIA CRUDE OIL—Continued

Year	Highest	Lowest
1880	1.24⅜	.71¼
1881	1.01¼	.72½
1882	1.35	.49¼
1883	1.24¾	.83¼
1884	1.15⅝	.51¼
1885	1.12⅝	.68
1886	.92¼	.60
1887	.90	.54
1888	1.00	.71⅜
1889	1.12½	.79½
1890	1.07⅞	.60¾
1891	.81⅝	.50
1892	.64⅛	.50
1893	.80	.52⅞
1894	.95¾	.78½
1895	2.60	.94½
1896	1.50	.90
1897	.96	.65
1898	1.19	.65
1899	1.66	1.13
1900	1.68	1.05
1901	1.30	1.05
1902	1.54	1.15
1903	1.90	1.60
1904	1.85	1.50
1905	1.61	1.27
1906	1.64	1.58
1907	1.78	1.58
1908*	1.78	1.78
1909	1.78	1.43
1910	1.43	1.30
1911	1.35	1.30
1912	2.00	1.35
1913	2.50	2.00
1914	2.50	1.45
1915	2.25	1.36
1916	2.75	2.25
1917	3.75	2.95
1918	4.00	3.75
1919	5.00	4.00
1920	6.10	5.00
1921	6.10	3.00

* One price the whole year.

EVAPORATION LOSSES OF CRUDE OIL AND THEIR ELIMINATION IN THE MID-CONTINENT FIELD*

The purpose of this paper is to bring before the oil industry in a concise way, one of the largest losses to which petroleum is subjected under the present methods of handling and storing. For detailed results of 18 month's work on this subject by the author of this paper, refer to Bulletin 200 of the U. S. Bureau of Mines. (Bulletin 200, Evaporation Losses of Crude Oil in the Mid-Continent Field, by J. H. Wiggins.) The scope will be limited to:

1. A very brief description of the present methods of handling crude oil.

2. A statement of approximate loss in various stages of handling crude oil.

3. Probable future developments in handling crude.

General Statements Regarding Evaporation Losses—It is possible to eliminate from two-thirds to four-fifths of the evaporation loss of crude, by protecting the oil from free contact with air and such protection will pay for itself in a short time.

The part of the crude that is lost through evaporation is the most volatile part of the gasoline fraction. For this reason the value of the part lost is much greater than the value of the crude itself. This causes the percentage of the value lost to be two or three times the percentage of the volume lost.

Over one-half of the total evaporation loss of the crude occurs during the first few days that it is handled on the lease.

Two very flagrant examples of overlooking evaporation losses are:

1. Dehydration in open tanks by forcing the oil through hot water.

2. Over-shot connections for filling an open stock tank.

* By J. H. Wiggins, Bureau of Mines.

The gasoline fraction while still in crude oil will evaporate from one-half to six-tenths as rapidly as the commercial gasoline which is taken from that crude, evaporative conditions in both cases being the same.

The estimated loss of gasoline from the crude produced in the Mid-Continent field alone in 1919 was just about equal to the total casinghead gasoline produced in the whole United States that year namely about 510,000,000 gallons. (See Fig. 156.) Thus it is seen that what one might call a new industry lies dormant, namely the saving of evaporation losses.

The latter statement leads to the consideration of how evaporation losses of crude will be eliminated. There are two ways (1) either keep the gasoline in the crude until it gets to the refinery or (2) take out the most volatile fractions, on the lease, say from seven to ten per cent and handle this very small fraction very carefully so that it will suffer no evaporation loss.

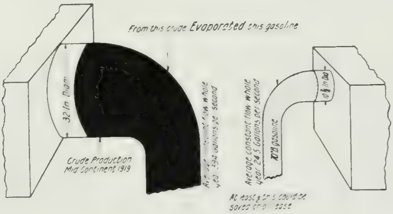


Fig. 156

The Present Methods of Handling Crude—Crude oil is pumped from the well through a small pipe into a tank which is used to separate either water, gas or sediment from the oil. The crude is generally sprayed into this tank from an over-shot connection and the surface of the oil has very free exposure to the air.

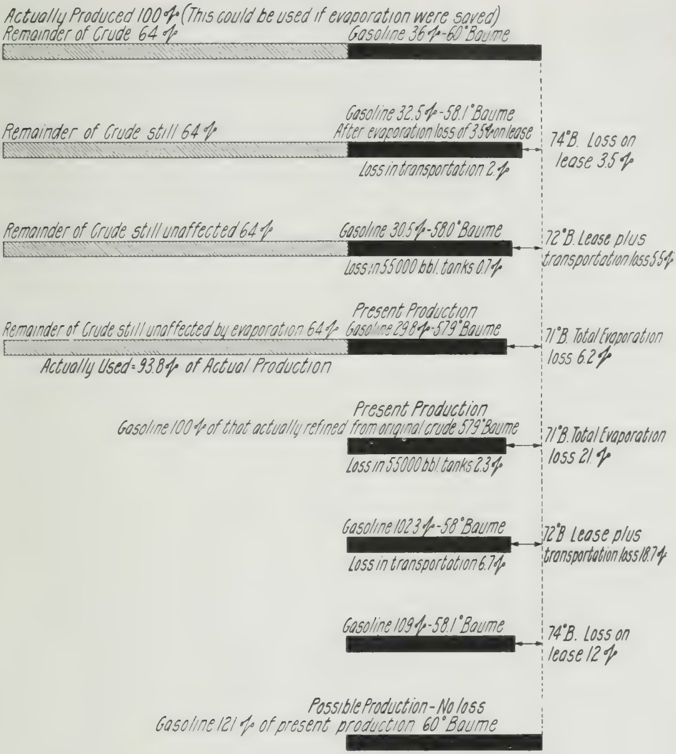


Fig. 157

From the above separating tank the oil is gravitated into the stock tank of the lease where it is again splashed from an over-shot connection. The average period that it takes to fill and market the lease stock tank is approximately five to seven days.

From the above tank the oil is picked up by the pipe line company which handles it through large pipes and tanks or tank cars to its destination at the refinery. The pipe line tanks have nearly gas-tight roofs and their connections are at the bottom of the tank which causes only a violent

stirring effect instead of the splashing and spray of the over-shot connection. Consequently their evaporation loss is much less than occurs on the lease in the same period of time.

A classification according to rate of evaporation per unit of time for various methods of handling crude may be made. In this classification it is assumed that the same oil is used. They are placed in the order of the greatest loss at the beginning and the least loss per unit of time, at the end.

1. Filling a tank by over-shot connections. This represents the highest loss per unit of time and is an example of loss through spray.

2. Filling a tank with bottom connections, where the oil is run into the bottom of the tank without being exposed to the air except at the surface. This class has a somewhat slower rate and represents loss aggravated by ebullition.

3. The storage of oil in small tanks which are not protected from the sun's rays nor from the free circulation of air.

4. The storage of oil in small tanks wherein it is protected somewhat both from the sun and free air circulation.

5. The storage of oil in the large 37,500 or 55,000 barrel standard steel tanks. The last three represent losses from still surfaces or surfaces agitated by wind only.

There are a number of things that cause a change in the rate of evaporation, among which are the volatility of the gasoline contained in the crude, the amount of gasoline contained and the amount of gas dissolved in a crude. The greatest single cause of variation in rate, however, is in the method of handling the oil.

Losses in Various Stages of Handling Crude Oil—It has been previously stated that over one-half of the total evaporation loss of crude occurred during the first few days that the oil was on the lease. These losses occur: (1) In the flow tank, (2) During filling the lease stock tank and (3) During standing in the lease stock tank. Moreover, there is a con-

siderable loss after it leaves the latter tank by the pipe line company, which may be separated into (1) Gathering the oil from the lease tanks to the first large pipe line tank, (2) Transportation by the pipe line, (3) Storage in 55,000-barrel tanks on tank farms or at the refinery. For the average conditions all the year around, the following percentages of evaporation loss from the crude produced have been determined.

1. On the lease:
   (a) Flow tank, one per cent.
   (b) Filling the lease stock tank, 1 per cent.
   (c) Storage in lease stock tank, 1.5 per cent.
2. Pipe line company losses:
   (a) Gathering, 1 per cent.
   (b) Transportation, 1 per cent.
   (c) Storage on tank farm, 0.7 per cent. Added,

this gives the startling total of 6.2 per cent of the oil produced which evaporates before it reaches the refinery. This 6.2 per cent has been determined by charging the loss against the total volume of the crude. As before mentioned, the fraction evaporated is the best part of the gasoline, and so it may be figured that if the crude normally yields 24 per cent gasoline as it reaches the refinery, it would have yielded about 30 per cent if no evaporation had been allowed. Thus it is easily seen that over 20 per cent of the straight run gasoline production of the Mid-Continent crude is lost. In other words, the straight run gasoline produced could be increased by over 20 per cent if all evaporation losses were eliminated. This leads to the consideration of what steps may be and probably will be taken for the elimination of evaporation losses. (See Fig. 157.)

Probable Future Developments in Handling Crude—There are two distinct ways to overcome evaporation losses of crude oil: The first is to keep the gasoline in the crude by protecting the oil from the air and keeping it under a

slight pressure if necessary. The second is to take out the most volatile fractions say 7 to 10 per cent of the crude before transportation to the refinery and to handle this small fraction in such a way that it will not suffer from evaporation.

There are arguments for and against both of the above propositions.

Consider first only the loss on the lease. It is seen here that on the average the loss is conservatively 3½ per cent, and in the summer time this rises as high as about 4½ per cent of the crude, representing the most volatile fraction thereof. Since the oil is "topped" by these amounts, by the present methods of handling, the remainder represents a much less volatile liquid. By making all flow tanks and stock tanks absolutely gas-tight and keeping a very slight pressure on them, perhaps four-fifths or more of this evaporation could be eliminated. In other words, these very volatile fractions which are ordinarily evaporated would be kept in the oil and it would still be a fluid which has nearly the original volatility of the crude from the well. The producer would be selling more oil and oil of a higher gravity.

If the 3½ per cent to 4½ per cent of the crude were by some means taken from it and conserved as gasoline, then the crude delivered to the pipe line would be the same as the crude that has been delivered to the pipe line, heretofore subjected to the ordinary amount of evaporation. Under this condition the refiner is standing no loss that he has not been standing always. In addition, a very large quantity of gasoline would be added to the production of the United States. Also the producer of the crude would find a very profitable business in the recovery of such gasoline.

Pipe Line Losses—By examination of the table given above, it is seen that the pipe line evaporation losses are about 2.7 per cent on the average. This rises in the summer time to about 3.5 per cent. Thus it is seen that even after the oil leaves the lease and has been "topped" by evaporation

3½ per cent to 4½ per cent, still it is subjected to a very considerable evaporation loss. Under the conditions of lease operation above described, namely wherein the gasoline is kept in the crude, the oil will leave the lease as a much more volatile liquid than formerly. In fact, the crude that the pipe line would now receive would lose from two to three times as much for the same evaporation conditions. If under present conditions of handling, the pipe line company loses 3 per cent it can be estimated conservatively, they would lose in the neighborhood of from 5 to 5½ per cent when all of the gasoline has been retained in the oil while on the lease. Thus it is seen that whereas about 3½ per cent of gasoline has been kept in the crude on the lease, from 2 to 2½ per cent of this saving will later be lost by the transportation company, showing only a net saving to the United States production of about 1 per cent to 1½ per cent. The above are sample figures based upon knowledge of present losses.

Now, in order to make a complete saving of the benefits derived from keeping the gasoline in the crude on the lease, it will be necessary never to expose oil to the air in the pipe line tanks. In case of measuring stations, this is impossible unless very large gasometers are installed. At a measuring station, for instance, the filling of a 55,000-barrel tank, when calculating only the displacement of air and vapor during filling, shows a loss of gasoline amounting to about 1400 gallons. That figure is calculated at the rate of 20 per cent gasoline vapor and 80 per cent air. The extra installation along pipe lines would be rather costly compared to the installation on the leases. In order to keep most of the gasoline in the crude until it reaches the refinery, it is necessary to make the gas tight installations **both on the lease and pipe line.**

If, however, instead of keeping the gasoline in the crude on the lease, 3½ per cent to 4½ per cent had been taken out and preserved as gasoline, then the oil that the pipe line received would be the same oil that it now receives and the

pipe line loss would be the same as now, namely from 2.7 per cent to 3.5 per cent.

If, instead of taking out only 3½ per cent to 4½ per cent on the lease, the producer should take out from 7 to 10 per cent, then the oil that the pipe line received would be very much less volatile. The loss of the pipe line company, due to evaporation, would under the above conditions be for the same evaporation conditions during transportation, only about 0.7 per cent to 0.9 per cent. These figures are based on a study of evaporation losses by pipe line companies in conjunction with evaporation curves on crude oil which was subjected to constant conditions. If crude oil loses 10 per cent in twenty days time, then in the next similar twenty days it will lose only an additional 3 per cent, showing its volatility is something less than one-third of what it originally was.

Presuming that the producer extracted 7 per cent of the crude as it leaves the well, the pipe line company would deliver to the refiner the original crude less 7.7 to 7.9 per cent. This represents the 7 per cent extracted by the producer plus 0.7 to 0.9 per cent evaporation loss of the pipe line. Under present conditions of handling and storing crude, the pipe line is actually delivering to the refiner the original crude minus 7.6 per cent in the summer and minus 6.2 per cent on the average the whole year around. Thus it is seen that the extraction of 7 per cent of the crude as gasoline on the lease would probably cause little if any less gasoline reaching the refiner than he has been receiving under present conditions of handling. Of course, all tanks on the lease would be evaporation proof under the assumption of extraction of gasoline, so that only what is normally the evaporation loss portion would be taken out.

The figures on evaporation on the lease and of the pipe line company are very conservative. There are cases which have come under observation where the loss from well to

refinery in less than ten days was 9.3 per cent. Counting the time that oil is held on the lease, in the pipe line, storage tank farms and in the refinery storage, the average time elapsed between the well and the stills at the refinery is nearly six months. Cases under observation have shown a loss of 6 per cent of the original volume of crude during a single transfer, namely from one tank to another under aggravated conditions.

The cost of keeping the gasoline in the crude would be much less than the cost of extracting it. This is because the extraction method as far as operations on the lease are concerned, would to a certain extent, involve the installation necessary to eliminate the evaporation of the crude plus the machinery for taking out the gasoline. A point to be noted here is that those who already have a gasoline plant on the lease, have part of the installation necessary for extracting the gasoline from the crude, which otherwise would evaporate. It is a matter for determination by the engineer, the benefits and expenses of each of the methods discussed. The extraction on the lease would, however, cut down the evaporation loss of the transportation company enormously, without making any changes in their plants.

In either case, that is, taking out the gasoline or keeping it in the crude, the producer should be paid for his oil on a more scientific basis. It is easy to see that if a producer does keep the gasoline in his oil, he should not only be paid for the additional quantity that he sells, but also should be paid for the better quality of crude that he is selling. He has raised the gravity of his oil an appreciable amount. If he were paid on the gravity basis, he would realize an enhanced unit as well as an increased quantity value of his crude.

If now, another producer should take out 5 to 10 per cent, this one should still be paid on the gravity basis because the oil that he would be delivering would not be so good as that which the producer delivers, who keeps the gasoline in his crude."

Table 137—GRAVITY OF OILS

The following table gives the gravity grade of Mid-Continent crude and that of other fields:

District	Gravity
Paola, Kansas	31.4
Rantoul, Kansas	30.9
Allen county, Kansas	22 to 28
Neosho county, Kansas	28 to 30
Montgomery county, Kansas	28 to 32
Chautauqua county, Kansas	32 to 34
Cherryvale, Kansas	36.6
Augusta, Kansas	32 to 34
Greenwood county, Kansas	39.8
Eldorado, Kansas	35 to 38
Blackwell, Oklahoma, deep	37 to 40
Blackwell, shallow	42.7
Newkirk, Oklahoma	37 to 39
Ponca City, Kansas	37 to 40
Glenn Pool, Oklahoma	36 to 38
Henryetta, Oklahoma	28 to 37
Bald Hill, Oklahoma	35 to 37
Muskogee, Oklahoma	34 to 39
Bird Creek, Oklahoma	26 to 35
Healdton, Oklahoma	27 to 32
Cushing, Oklahoma	37 to 40
Fox Pool, Oklahoma	45
Nowata, Oklahoma	30 to 34
Osage	36
Garber	38 to 50

OTHER FIELDS

District	Gravity
California—	
San Joaquin Valley	14 to 29
Los Angeles county	16 to 32
Ventura county	25 to 30
Fresno county	18 to 30
Coast fields	16 to 28

The following table gives the gasoline and kerosene percentages from Mid-Continent crude:

District Produced	Kerosene Per Cent.	Gasoline Per Cent.
Kansas—		
Northern districts	28	8 to 13
Montgomery county	25	12
Chautauqua county	24	15
Cowley county	..	18 to 20
Augusta	20	15.5 to 20
Eldorado	24	18 to 22
Greenwood county	..	39.8
Cherryvale	20	12
Paola and Rantoul	21	13

District Produced Oklahoma—	Kerosene Per Cent.	Gasoline Per Cent.
Blackwell, shallow	..	30 to 40
Blackwell, deep	..	18 to 25
Bixby	..	18 to 23
Leonard	..	23 to 25
Stone Bluff	..	20 to 23
Dewey, deep	20	5.5
Dewey, shallow	28	12
Bartlesville	23	10
Osage	25	20
Ponca	25	22
Cleveland	28	14
Cushing	25	22 to 30
Fox Pool	25	30
Cole Pool	..	13
Healdton	26	9 to 11
Healdton, light	..	15 to 17
Garber special	..	55
Nowata	23	15 to 16

Fig. 158

Flow of Fluids in Smooth Pipes*—Oil presents to the engineer in a forceful way the characteristics of all fluids—whether liquids or gases—when flowing in smooth straight circular pipes.

Scientists have tried for a number of years to develop mathematical expressions which would describe fluid flow for all velocities. While it was possible to establish expressions which would accurately describe stream-line flow, such expressions did not apply to turbulent motion. It was found that with a given pipe a certain velocity could be reached at which stream-line flow broke down and changed to a state of turbulence, but after turbulence had occurred it, in turn, would give way to a condition of steady flow—the fluid no longer moving in stream lines. At this point investigators usually found themselves baffled.

In recent years, however, new efforts have been made and the classic work of T. E. Stanton and J. R. Pannell† has shown once and for all that steady flow obeys quite definite laws and that these laws apply to every fluid whether liquid or gas. This information is of inestimable value to the engineer in the oil industry, and the following brief discussion and curves will be found convenient in understanding and calculating the flow through pipe lines.

Every engineer is familiar with critical speeds of turbine shafts. We all know that a turbine shaft will start up very smoothly and if the speed is increased sufficiently, we will reach a point where violent vibration occurs. After a short time, if the speed be increased, smooth operation will again occur and additional increases of speed will not be accompanied by any further disturbance. As a matter of fact, the operation is more stable above the critical speed than below it. This occurrence is occasioned by the fact that a new distribution of stress within the shaft has

* Courtesy of Power Specialty Co.
† See Philosophical Transactions, Royal Society, Vol. 214, 1914.

taken place, and it is at the point of transition from the old stress arrangement to the new one that the unstable conditions occur which result in the critical speed.

Flowing fluids seem to possess the same ability to change from one state of stable equilibrium to another, and when this change occurs we have what is called the critical velocity of the fluid.

The critical velocity manifests itself in a variety of ways. The most noticeable and immediately observable indication is that a considerable increase in pipe line pressure does not result in a corresponding increase of discharge. If we were to observe a given pipe through which a fluid is passing, we would notice that at very slow speeds the fluid seems to move as though it were made up of an infinite number of cylindrical shells, having infinitesimal thickness, sliding past one another at different speeds, so that the cylinder nearest the pipe wall would remain stationary, the next one would have a slightly higher velocity with respect to the pipe, and so on until we came to the center where the highest velocity would prevail. It would be found that the velocity of the center point would be about twice the average velocity of flow through the pipe. If we were to increase the pressure gradually, thereby increasing our fluid velocity, we would at length reach a point where the fluid suddenly broke down and became turbulent. We would find that increasing the pressure a considerable amount would produce only slight increases in velocity. This is the point of unstable flow and at this point the whirls and eddies formed do not take on any systematic conformation. However, on further increasing the pressure we find that our discharge increases a proportionate amount. Our fluid is now in a new state of equilibrium, not flowing in stream lines, but rather rolling through the pipe with vortex motion. This is called the state of steady flow, which means that pressure and velocity remain constant

at any given point in the line, so that if we should get a pressure and velocity reading at any given point, it would remain constant at all times. It is interesting to note that beyond the critical velocity—with given pipe and fluid condition—K decreases with an increase of velocity and at high velocities the frictional loss tends to become proportional to the square of the velocity.*

From the point of view of pipe line design, and also oil-still design, exceeding the critical velocity is an important matter. In the oil still, turbulent flow produces a constant temperature throughout the cross section of the pipes. The heated outer layers of oil are constantly carried into the cooler core of the pipe. This prevents unnecessary carbonization. In the case of pipe lines carrying heated oil, the use of velocities in excess of the critical velocity will prevent to a large extent the cooling of the oil in contact with the pipe and the corresponding increase in viscosity in this region.

Viscosity may be described as the resistance to internal movement, one upon another, of the particles composing a gas or liquid. It is the internal friction of the fluid. Viscosity plays a most important part in all problems dealing with fluid flow; in oil, especially, because the viscosity of oil changes greatly with changes in temperature.

Absolute viscosity in the centimeter-gram-second system of units is the force in dynes necessary to move a surface of one square centimeter in area past another parallel surface of equal area with a velocity of one centimeter per second, the two areas being one centimeter apart and the intervening space being filled with the viscous fluid.

The absolute viscosity is given in dynes per square centimeter. The unit of absolute viscosity is called the poise and is equal to one dyne per square centimeter.

A smaller unit is sometimes used—called the centipoise. This is equal to .01 poises.

* See page 572—Curves.

Water at 20 degrees centigrade (68 degrees fahrenheit) has a viscosity of 1.0050 centipoises.*

The kinematic viscosity is absolute viscosity divided by the specific gravity.

The critical velocity of a fluid is given by the equation

$$\frac{D\,v_c}{\nu} = k \text{ or } v_c = k\frac{\nu}{D}$$

where D is the diameter, v_c is the critical velocity, k a constant and ν is the kinematic viscosity. It is seen, therefore, that the critical velocity is directly proportional to the kinematic viscosity. It is evident that for large values of ν such as are found for heavy cold oils v_c becomes so large that an effort to exceed the critical velocity would involve very high pumping pressures and excessive pressure losses in the pipe line due to friction.

Where ν is small as is the case for heated oils, then v_c is also small and velocities in excess of the critical velocity are permissible due to reasonable friction losses in pipe lines under these conditions.

In calculating pipe lines, the viscosity at various temperatures at which operation may take place must be analyzed, because frequently it will be found that for one range of operation, velocities will be below the critical value on account of the high viscosity, whereas at higher temperatures the velocity will be in excess of the critical velocity because of the lower viscosity at the higher temperature. In selecting pumping equipment sufficient pressure must be provided to make good the loss in overcoming the critical velocity.

The viscosity of oils is measured with a viscosimeter. The three principal instruments in use are the Universal Saybolt, used exclusively in this country, the Redwood used largely in England, and the Engler which is

* Bureau of Standards. Scientific Paper 298, p. 75.

standard in Germany. All of these instruments are built on the same principle, viz., they are designed with a capillary tube through which a measured quantity of oil escapes, the time of escape and temperature of the oil being noted. The Saybolt viscosity is the time in seconds required for the escape of 60 cc. of the oil tested. Water has a viscosity of 30 seconds Saybolt, at 60 degrees fahrenheit.

The Engler viscosity, usually expressed in Engler degree or Engler number, is the ratio of the time of efflux of 200 cc. of oil and an equal amount of water.

The Engler degree for water is one. The time of efflux of 200 cc. of water at 20 degrees centigrade (68 degrees fahrenheit) is 52 to 53 seconds. The Bureau of Standards has adopted the standard time of 51.3 seconds.

The Redwood viscosimeter is calibrated with rape oil—a thick vegetable oil. It requires 535 seconds for the efflux of 50 cc. of this oil at 60 degrees fahrenheit, and the viscosity of an oil is usually expressed as a percentage of time required for the passage of 50 cc. of the rape oil. The time of efflux of 50 cc. of water at 60 degrees fahrenheit is about 25½ seconds. It should be noted that viscosimeters of the same type will show slight variations in readings for the same oil due to slight differences in dimensions of capillary tubes and other parts.

Figure 159 shows the relation between readings on the various instruments and the corresponding kinematic viscosities. To illustrate its use assume the Engler degree 4.4 is given and it is required to find the kinematic viscosity and also the Saybolt seconds and Redwood seconds.

Follow the line 4.4 down from the Engler degree scale to the Engler curve. From the intersection read to the left on a horizontal line. This will give the corresponding kinematic viscosity as .31. If we read to the right from the intersection on a horizontal line until we intersect

the Saybolt curve and from this point down, we obtain 148 Saybolt seconds corresponding to 4.4 Engler degree. In a similar way we find the corresponding Redwood seconds to be 123.

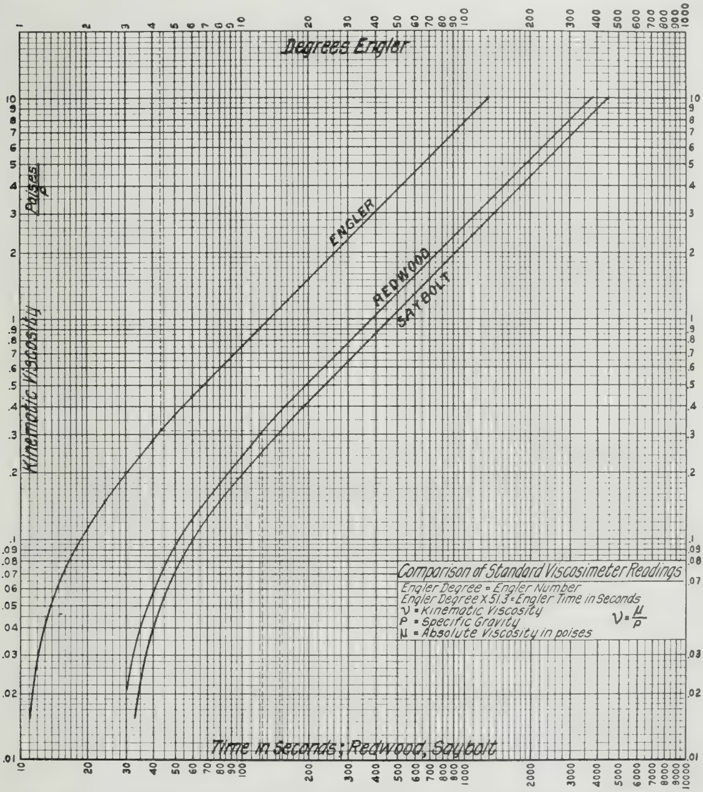


Fig. 159—COMPARISON OF STANDARD VISCOSIMETER READINGS
See Page 570.

For viscosimeter readings greater than those shown on the curve, the corresponding kinematic viscosities may be calculated by the formulas used by the Bureau of Standards.

Kinematic viscosity $= 0.00220S - \frac{1.80}{S}$ for Universal Saybolt viscosimeter

Kinematic viscosity $= 0.00147E - \frac{3.74}{E}$ for Engler viscosimeter

Kinematic viscosity $= 0.00260R - \frac{1.715}{R}$ for Redwood viscosimeter

S = Saybolt, E = Engler and R = Redwood seconds.

The viscosity of an oil is greatly decreased by increasing its temperature, the greatest viscosity change occurring up to about 150 degrees fahrenheit. Above this temperature the rate of change in viscosity, with respect to temperature, decreases. The viscosity of a heavy oil can also be decreased by mixing it with a lighter oil.

It has been found that oils of a given density when heated expand corresponding to a well-defined law, and that all oils of the same density at 60 degrees fahrenheit will obey the same law.

The change in viscosity of an oil with respect to temperature does not seem to conform to any law whatever, oils of the same viscosity at a given temperature showing wide variations in viscosity at all other temperatures.

Pressure loss due to friction in pipes is expressed by the general equation—

$$P = K \frac{Q^2 p}{D^5}$$

where P = pressure loss in pounds per square inch per 1,000 feet length,
Q = quantity of fluid flowing in barrels per hour,
p = specific gravity, compared to water,
D = inside diameter of pipe in inches,
K = a number depending upon Q, D and ν,
ν = kinematic viscosity.

NOTE—Units of measurement changed in this article by the author.

Figures 160 and 161 give values for K both below and above the critical velocity, respectively, plotted against the ratio $\frac{Q}{D\nu}$. Between the values of $\frac{Q}{D\nu}$ =80 to 140, the curve has not been plotted, since between these limits unstable flow conditions prevail.

All curves and formulas given here are based upon the use of smooth drawn tubing and the curves apply to geometrically similar pipes. This means that the roughness or inequalities must be in the same ratio as the pipe diameters.

If the inequalities are in a greater ratio, then the curves will be correspondingly slightly higher. However, in oil work the curves as plotted will be sufficiently accurate. It is assumed, of course, that the pipes are made up with reasonable care and are of commercial quality. Where screwed fittings are used the ends of pipes should be reamed. This is especially important when handling heavy oils.

The two following examples illustrate the use of the curves in Figures 160 and 161.

Example 1

Find the pressure loss per 100 feet of pipe having 10 inch inside diameter with oil flowing at the rate of 1,070 barrels per hour. The oil has a kinematic viscosity $\nu = 27.0$, and a specific gravity of .96.

1st step. Evaluate $\frac{Q}{D\nu}$

$$\frac{Q}{D\nu} = \frac{1070}{10x27} = 3.96$$

2d step. Find K corresponding to $\frac{Q}{D\nu} = 3.96$ on curve, Figure 160. K=4.85.

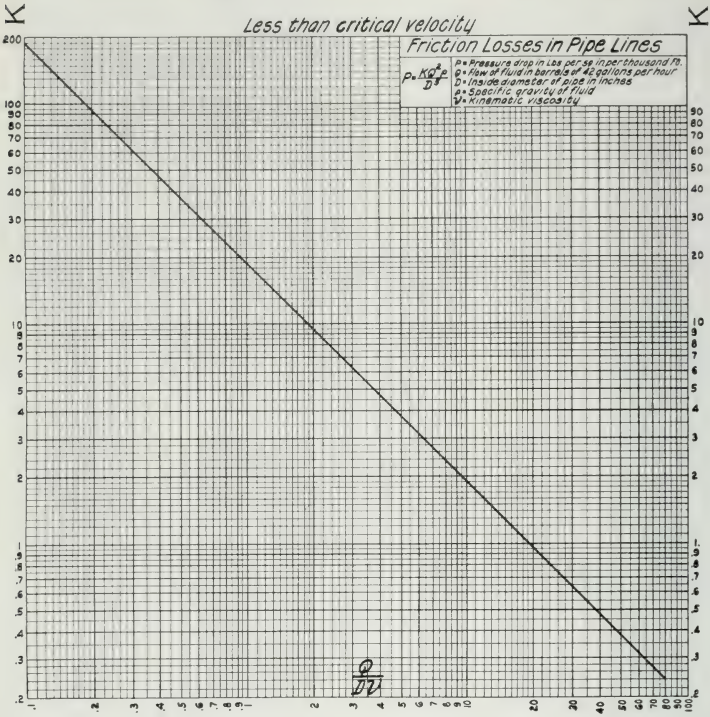


Fig. 160

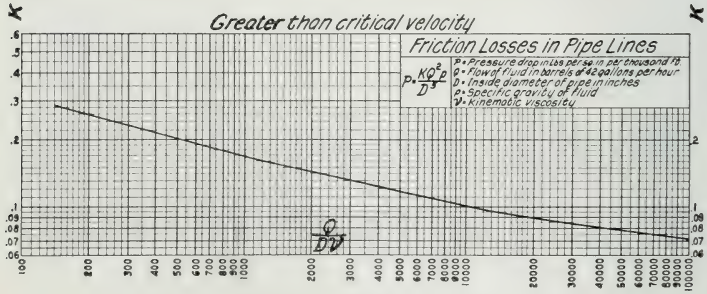


Fig. 161—FRICTION LOSSES IN PIPE LINES

Adapted from Stanton and Pannels' experiments, Proc. Royal Society, Vol. 91, 1914, Phila. Trans. Royal Society, Vol. 214, 1914.

3d step. Find the value of P from the general equation

$$P=\frac{KQ^2\rho}{D^5}$$

$$P=\frac{4.85 \times (1070)^2 \times .96}{10^5}=53 \text{ lb. per sq. in. per } 1000$$

feet length, or 5.3 lb. pressure drop for 100 feet of pipe.

The velocity will be below the critical value since K was found from Figure 160.

Example 2

Find the pressure loss per 100 feet of 4 inch inside diameter pipe when 800 barrels of oil per hour are flowing, the oil having a viscosity of 110 Saybolt seconds and a specific gravity of .90.

1st step. From Figure 159 we see that 110 Saybolt seconds correspond to kinematic viscosity $\nu=.222$.

$$\frac{Q}{D\nu}=\frac{800}{4 \times .222}=901.$$

The corresponding K is found on Figure 161 equal to .173 and $P=\frac{.173 \times (800)^2 \times .90}{4^5}=97$ lb. per sq. in. per 1000 feet or pressure drop for 100 ft. is 9.7 lb. per sq. in. The velocity is greater than the critical value since K was found from Figure 161.

A handy rule for determining the critical velocity is given below.

The critical velocity range begins when

$$\frac{Dv_c}{\nu}=25 \text{ or } v_c=\frac{25\,\nu}{D}$$

and it ends when

$$\frac{Dv_c}{\nu}=40 \text{ or } v_c=\frac{40\,\nu}{D}$$

where D = inside diamater of pipe in inches.

v_c = critical velocity in feet per second.

ν = kinematic viscosity.

From this it follows that when $\frac{Dv}{\nu}$ is less than 25, we have stream line flow, and when $\frac{Dv}{\nu}$ is greater than 40 we have steady flow, where v is the velocity in feet per second.

The curves which precede are useful in solving many problems in fluid flow.

Tables on pages 582 and 584 show the change of specific gravity for changes of temperature.

Fig. 162

PART NINETEEN

MISCELLANEOUS

Baume Scale and Specific Gravity Equivalent — The instruments used are a hydrometer and a standard thermometer. The hydrometer, which is a glass column marked with graduations from 10 to 100, was invented by Antoine Baume, a French chemist, and the scale on the instrument has always borne his name. The hydrometer, when placed in a jar or a bottle of oil, sinks to the point on the scale which indicates the gravity in degrees Baume. There are two Baume hydrometers—one which is used with liquids heavier than water with which the hydrometer sinks to 0 degrees in pure water and to 15 degrees in a 15 per cent salt solution; the other for liquids lighter than water which sinks to 0 degrees in a 10 per cent salt solution and to 10 degrees in pure water. With both hydrometers the graduations are based on the densities between the fundamental points and are continued along the stem of the hydrometer as far as desired.

The basis of temperature for testing oil is 60 deg. fahr., and for oil at a greater or less temperature, variations must be calculated. Hydrometers are usually provided with a special scale for figuring temperature variations.

All degrees on a Baume scale are thus equal in length while those on a specific gravity scale grow smaller as the density increases.

Method of Reading the Hydrometer*—The correct method of reading the hydrometer is illustrated in Figs. 163 and 164. The sample of oil is placed in a clear glass jar or cylinder and the hydrometer carefully immersed in it to a point slightly below that to which it naturally sinks, and is then allowed to float freely.

* Circular of the Bureau of Standards No. 57.

HYDROMETER READING

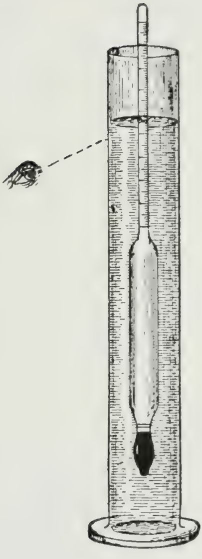


Fig. 163

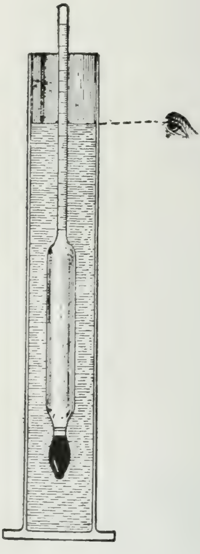


Fig. 164

The reading should not be taken until the oil and the hydrometer are free from air bubbles and are at rest.

In taking the reading the eye should be placed slightly below the plane of the surface of the oil, Fig. 163, and then raised slowly until this surface, seen as an ellipse, becomes a straight line, Fig. 164. The point at which this line cuts the hydrometer scale should be taken as the reading of the instrument, Fig. 164.

In case the oil is not sufficiently clear to allow the reading to be made as above described, it will be necessary to read from above the oil surface and to estimate as accurately as possible the point to which the oil rises on the hydrometer stem. It should be remembered, however, that the instrument is calibrated to give correct indications when read at the principal surface of the liquid. It will be necessary, therefore, to correct the reading at the upper meniscus by an amount equal to the height to which the oil creeps up on the stem of the hydrometer. The amount of this correction may be determined with sufficient accuracy for most purposes by taking a few readings on the upper and the lower meniscus in a clear oil and noting the differences.

A specific gravity hydrometer will read too low and a Baume hydrometer too high when read at the upper edge of the meniscus. The correction for meniscus height should therefore be added to a specific gravity reading and subtracted from a Baume reading.

The magnitude of the correction will obviously depend upon the length and value of the subdivisions of the hydrometer scale and must be determined in each case for the particular hydrometer in question.

Table 138—SPECIFIC GRAVITY TO DEGREES BAUME

Degrees Baume, and Pounds per Gallon, Corresponding to the Various Specific Gravities Designated

Specific gravity at 60°/60°F	Degrees Baume	Pounds per gallon	Specific gravity at 60°/60° F	Degrees Baume	Pounds per gallon
0.600	103.33	4.993	0.650	85.38	5.410
.601	102.94	5.001	.651	85.05	5.418
.602	102.56	5.010	.652	84.72	5.426
.603	102.17	5.018	.653	84.40	5.435
.604	101.79	5.026	.654	84.07	5.443
.605	101.40	5.035	.655	83.74	5.452
.606	101.02	5.043	.656	83.42	5.460
.607	100.64	5.051	.657	83.09	5.468
.608	100.26	5.060	.658	82.77	5.476
.609	99.88	5.068	.659	82.44	5.485
.610	99.51	5.076	.660	82.12	5.493
.611	99.13	5.084	.661	81.80	5.502
.612	98.76	5.093	.662	81.48	5.510
.613	98.38	5.101	.663	81.16	5.518
.614	98.01	5.110	.664	80.84	5.526
.615	97.64	5.118	.665	80.53	5.535
.616	97.27	5.126	.666	80.21	5.543
.617	96.90	5.135	.667	79.90	5.552
.618	96.54	5.143	.668	79.58	5.560
.619	96.17	5.151	.669	79.27	5.568
.620	95.81	5.160	.670	78.96	5.577
.621	95.44	5.168	.671	78.64	5.585
.622	95.08	5.176	.672	78.33	5.593
.623	94.72	5.185	.673	78.02	5.602
.624	94.36	5.193	.674	77.72	5.610
.625	94.00	5.201	.675	77.41	5.618
.626	93.64	5.210	.676	77.10	5.627
.627	93.28	5.218	.677	76.80	5.635
.628	92.93	5.226	.678	76.49	5.643
.629	92.58	5.235	.679	76.19	5.652
.630	92.22	5.243	.680	75.88	5.660
.631	91.87	5.251	.681	75.58	5.668
.632	91.52	5.260	.682	75.28	5.677
.633	91.17	5.268	.683	74.98	5.685
.634	90.82	5.276	.684	74.68	5.693
.635	90.47	5.285	.685	74.38	5.702
.636	90.13	5.293	.686	74.08	5.710
.637	89.78	5.301	.687	73.78	5.718
.638	89.44	5.310	.688	73.49	5.727
.639	89.09	5.318	.689	73.19	5.735
.640	88.75	5.326	.690	72.90	5.743
.641	88.41	5.335	.691	72.60	5.752
.642	88.07	5.343	.692	72.31	5.760
.643	87.73	5.351	.693	72.02	5.768
.644	87.39	5.360	.694	71.73	5.777
.645	87.05	5.368	.695	71.44	5.785
.646	86.72	5.376	.696	71.15	5.793
.647	86.38	5.385	.697	70.86	5.802
.648	86.05	5.393	.698	70.57	5.810
.649	85.72	5.402	.699	70.29	5.818

From "Circular of the Bureau of Standards No. 57."

Table 139—SPECIFIC GRAVITY TO DEGREES BAUME

Degrees Baume, and Pounds per Gallon, Corresponding to the Various Specific Gravities Designated

Specific gravity at 60°/60°F	Degrees Baume	Pounds per gallon	Specific gravity at 60°/60° F	Degrees Baume	Pounds per gallon
0.700	70.00	5.827	0.750	56.67	6.244
.701	69.72	5.835	.751	56.42	6.252
.702	69.43	5.843	.752	56.17	6.260
.703	69.15	5.852	.753	55.92	6.269
.704	68.86	5.860	.754	55.68	6.277
.705	68.58	5.868	.755	55.43	6.285
.706	68.30	5.877	.756	55.18	6.294
.707	68.02	5.885	.757	54.94	6.302
.708	67.74	5.894	.758	54.70	6.310
.709	67.46	5.902	.759	54.45	6.319
.710	67.18	5.910	.760	54.21	6.327
.711	66.91	5.918	.761	53.97	6.335
.712	66.63	5.927	.762	53.73	6.344
.713	66.35	5.935	.763	53.49	6.352
.714	66.08	5.944	.764	53.25	6.360
.715	65.80	5.952	.765	53.01	6.369
.716	65.53	5.960	.766	52.77	6.377
.717	65.26	5.968	.767	52.53	6.386
.718	64.99	5.977	.768	52.29	6.394
.719	64.72	5.985	.769	52.06	6.402
.720	64.44	5.994	.770	51.82	6.410
.721	64.18	6.002	.771	51.58	6.419
.722	63.91	6.010	.772	51.35	6.427
.723	63.64	6.018	.773	51.11	6.436
.724	63.37	6.027	.774	50.88	6.444
.725	63.10	6.035	.775	50.64	6.452
.726	62.84	6.044	.776	50.41	6.460
.727	62.57	6.052	.777	50.18	6.469
.728	62.31	6.060	.778	49.95	6.477
.729	62.04	6.068	.779	49.72	6.486
.730	61.78	6.077	.780	49.49	6.494
.731	61.52	6.085	.781	49.26	6.502
.732	61.26	6.094	.782	49.03	6.510
.733	61.00	6.102	.783	48.80	6.519
.734	60.74	6.110	.784	48.57	6.527
.735	60.48	6.119	.785	48.34	6.536
.736	60.22	6.127	.786	48.12	6.544
.737	59.96	6.135	.787	47.89	6.552
.738	59.70	6.144	.788	47.66	6.560
.739	59.44	6.152	.789	47.44	6.569
.740	59.19	6.160	.790	47.22	6.577
.741	58.93	6.169	.791	46.99	6.586
.742	58.68	6.177	.792	46.77	6.594
.743	58.42	6.185	.793	46.54	6.602
.744	58.17	6.194	.794	46.32	6.611
.745	57.92	6.202	.795	46.10	6.619
.746	57.67	6.210	.796	45.88	6.627
.747	57.42	6.219	.797	45.66	6.636
.748	57.17	6.227	.798	45.44	6.644
.749	56.92	6.235	.799	45.22	6.652

Table 140—SPECIFIC GRAVITY TO DEGREES BAUME

Degrees Baume, and Pounds per Gallon, Corresponding to the Various Specific Gravities Designated

Specific gravity at 60°/60°F	Degrees Baume	Pounds per gallon	Specific gravity at 60°/60° F	Degrees Baume	Pounds per gallon
0.800	45.00	6.661	0.850	34.71	7.078
.801	44.78	6.669	.851	34.51	7.086
.802	44.56	6.677	.852	34.32	7.094
.803	44.35	6.686	.853	34.13	7.103
.804	44.13	6.694	.854	33.93	7.111
.805	43.91	6.702	.855	33.74	7.119
.806	43.70	6.711	.856	33.55	7.128
.807	43.48	6.719	.857	33.36	7.136
.808	43.27	6.727	.858	33.17	7.144
.809	43.05	6.736	.859	32.98	7.153
.810	42.84	6.744	.860	32.79	7.161
.811	42.63	6.752	.861	32.60	7.169
.812	42.41	6.761	.862	32.41	7.178
.813	42.20	6.769	.863	32.22	7.186
.814	41.99	6.777	.864	32.04	7.194
.815	41.78	6.786	.865	31.85	7.203
.816	41.57	6.794	.866	31.66	7.211
.817	41.36	6.802	.867	31.48	7.219
.818	41.15	6.811	.868	31.29	7.228
.819	40.94	6.819	.869	31.10	7.236
.820	40.73	6.827	.870	30.92	7.244
.821	40.52	6.836	.871	30.74	7.253
.822	40.32	6.844	.872	30.55	7.261
.823	40.11	6.852	.873	30.37	7.269
.824	39.90	6.861	.874	30.18	7.278
.825	39.70	6.869	.875	30.00	7.286
.826	39.49	6.877	.876	29.82	7.294
.827	39.29	6.886	.877	29.64	7.303
.828	39.08	6.894	.878	29.45	7.311
.829	38.88	6.902	.879	29.27	7.319
.830	38.68	6.911	.880	29.09	7.328
.831	38.47	6.919	.881	28.91	7.336
.832	38.27	6.927	.882	28.73	7.344
.833	38.07	6.936	.883	28.55	7.353
.834	37.87	6.944	.884	28.37	7.361
.835	37.66	6.952	.885	28.19	7.369
.836	37.46	6.961	.886	28.01	7.378
.837	37.26	6.969	.887	27.84	7.386
.838	37.06	6.978	.888	27.66	7.394
.839	36.87	6.986	.889	27.48	7.403
.840	36.67	6.994	.890	27.30	7.411
.841	36.47	7.002	.891	27.13	7.419
.842	36.27	7.011	.892	26.95	7.428
.843	36.07	7.019	.893	26.78	7.436
.844	35.88	7.028	.894	26.60	7.444
.845	35.68	7.036	.895	26.42	7.453
.846	35.48	7.044	.896	26.25	7.461
.847	35.29	7.052	.897	26.08	7.469
.848	35.09	7.061	.898	25.90	7.478
.849	34.90	7.069	.899	25.73	7.486

Table 141—SPECIFIC GRAVITY TO DEGREES BAUME

Degrees Baume, and Pounds per Gallon, Corresponding to the Various Specific Gravities Designated

Specific gravity at 60°/60°F	Degrees Baume	Pounds per gallon	Specific gravity at 60°/60° F	Degrees Baume	Pounds per gallon
0.900	25.56	7.494	0.950	17.37	7.911
.901	25.38	7.503	.951	17.21	7.920
.902	25.21	7.511	.952	17.06	7.928
.903	25.04	7.519	.953	16.90	7.937
.904	24.87	7.528	.954	16.75	7.945
.905	24.70	7.536	.955	16.60	7.953
.906	24.52	7.544	.956	16.44	7.962
.907	24.36	7.553	.957	16.29	7.970
.908	24.18	7.561	.958	16.14	7.978
.909	24.02	7.569	.959	15.98	7.987
.910	23.85	7.578	.960	15.83	7.995
.911	23.68	7.586	.961	15.68	8.003
.912	23.51	7.594	.962	15.53	8.012
.913	23.34	7.603	.963	15.38	8.020
.914	23.17	7.611	.964	15.23	8.028
.915	23.00	7.620	.965	15.08	8.036
.916	22.84	7.628	.966	14.93	8.045
.917	22.67	7.636	.967	14.78	8.053
.918	22.51	7.645	.968	14.63	8.062
.919	22.34	7.653	.969	14.48	8.070
.920	22.17	7.661	.970	14.33	8.078
.921	22.01	7.670	.971	14.18	8.087
.922	21.84	7.678	.972	14.03	8.095
.923	21.68	7.686	.973	13.88	8.103
.924	21.52	7.695	.974	13.74	8.112
.925	21.35	7.703	.975	13.59	8.120
.926	21.19	7.711	.976	13.44	8.128
.927	21.02	7.720	.977	13.30	8.137
.928	20.86	7.728	.978	13.15	8.145
.929	20.70	7.736	.979	13.00	8.153
.930	20.54	7.745	.980	12.86	8.162
.931	20.38	7.753	.981	12.71	8.170
.932	20.22	7.761	.982	12.57	8.178
.933	20.05	7.770	.983	12.42	8.187
.934	19.89	7.778	.984	12.28	8.195
.935	19.73	7.786	.985	12.13	8.203
.936	19.57	7.795	.986	11.99	8.212
.937	19.41	7.803	.987	11.84	8.220
.938	19.25	7.811	.988	11.70	8.228
.939	19.10	7.820	.989	11.56	8.237
.940	18.94	7.828	.990	11.41	8.245
.941	18.78	7.836	.991	11.27	8.253
.942	18.62	7.845	.992	11.13	8.262
.943	18.46	7.853	.993	10.99	8.270
.944	18.30	7.861	.994	10.84	8.278
.945	18.15	7.870	.995	10.70	8.287
.946	17.99	7.878	.996	10.56	8.295
.947	17.84	7.886	.997	10.42	8.303
.948	17.68	7.895	.998	10.28	8.312
.949	17.52	7.903	.999	10.14	8.320
			1.000	10.00	8.328

Table 142—TEMPERATURE CORRECTIONS TO READING OF SPECIFIC GRAVITY HYDROMETERS*

American Petroleum Oils at Various Temperatures
(Standard at 60°/60° Fahr).

Observed Temperature Deg. Fahr.	OBSERVED SPECIFIC GRAVITY.						
	0.650	0.700	0.750	0.800	0.850	0.900	0.950
	SUBTRACT FROM OBSERVED SPECIFIC GRAVITY.						
30	0.016	0.015	0.014	0.012	0.011	0.011	0.011
32	.015	.014	.013	.012	.011	.010	.010
34	.014	.013	.012	.011	.010	.010	.010
36	.013	.012	.011	.010	.009	.009	.009
38	.012	.011	.010	.009	.008	.008	.008
40	.0105	.0095	.0090	.0080	.0075	.0070	.0070
42	.0095	.0085	.0080	.0070	.0065	.0065	.0065
44	.0085	.0075	.0070	.0065	.0060	.0060	.0055
46	.0075	.0065	.0060	.0055	.0050	.0050	.0050
48	.0065	.0060	.0055	.0050	.0045	.0045	.0040
50	.0050	.0050	.0045	.0040	.0035	.0035	.0035
52	.0040	.0040	.0035	.0030	.0030	.0030	.0030
54	.0030	.0030	.0025	.0025	.0020	.0020	.0020
56	.0020	.0020	.0020	.0015	.0015	.0015	.0015
58	.0010	.0010	.0010	.0005	.0005	.0005	.0005
	ADD TO OBSERVED SPECIFIC GRAVITY.						
60	.0000	.0000	.0000	.0000	.0000	.0000	.0000
62	.0010	.0010	.0010	.0005	.0005	.0005	
64	.0020	.0020	.0015	.0015	.0015	.0015	
66	.0030	.0030	.0025	.0025	.0020	.0020	
68	.0040	.0040	.0035	.0030	.0030	.0030	
70	.0050	.0050	.0045	.0040	.0040	.0035	
72	.0060	.0055	.0050	.0045	.0045	.0040	
74	.0070	.0065	.0060	.0055	.0050	.0050	
76	.0080	.0075	.0070	.0065	.0060	.0055	
78	.0090	.0085	.0080	.0070	.0065	.0065	
80	.010	.009	.008	.008	.007	.007	
82	.011	.010	.009	.008	.008	.007	
84	.012	.011	.010	.009	.009	.008	
86	.013	.012	.011	.010	.009	.009	
88	.014	.013	.012	.011	.010	.010	
90	.015	.014	.013	.012	.011	.010	
92	.016	.015	.013	.012	.011	.011	
94	.017	.016	.014	.013	.012	.012	
96	.018	.016	.015	.014	.013	.013	
98	.019	.017	.016	.015	.014	.013	
100	.020	.018	.017	.015	.014	.014	
102	.021	.019	.018	.016	.015	.015	
104	.022	.020	.018	.017	.016	.015	
106	.023	.021	.019	.017	.016	.016	
108	.024	.022	.020	.018	.017	.017	
110	.025	.023	.021	.019	.018	.017	
112	.026	.024	.022	.020	.019	.018	
114	.027	.025	.022	.020	.019	.019	
116	.028	.026	.023	.021	.020	.019	
118	.029	.026	.024	.022	.021	.020	
120	.030	.027	.025	.023	.022	.021	

(* Circular No. 57 Bureau of Standards.)

Table 143—DEGREES BAUME TO SPECIFIC GRAVITY

Specific Gravities, and Pounds per Gallon, Corresponding to Various Degrees Baume

Degrees Baume (Modulus 140)	Specific Gravity 60°/60° F	Pounds per Gallon	Degrees Baume (Modulus 140)	Specific Gravity 60°/60° F	Pounds per Gallon
10.0	1.0000	8.328	55.0	0.7568	6.300
11.0	.9929	8.269	56.0	.7527	6.266
12.0	.9859	8.211	57.0	.7487	6.233
13.0	.9790	8.153	58.0	.7447	6.199
14.0	.9722	8.096	59.0	.7407	6.166
15.0	.9655	8.041	60.0	.7368	6.134
16.0	.9589	7.986	61.0	.7330	6.102
17.0	.9524	7.931	62.0	.7292	6.070
18.0	.9459	7.877	63.0	.7254	6.038
19.0	.9396	7.825	64.0	.7216	6.007
20.0	.9333	7.772	65.0	.7179	5.976
21.0	.9272	7.721	66.0	.7143	5.946
22.0	.9211	7.670	67.0	.7107	5.916
23.0	.9150	7.620	68.0	.7071	5.886
24.0	.9091	7.570	69.0	.7035	5.856
25.0	.9032	7.522	70.0	.7000	5.827
26.0	.8974	7.473	71.0	.6965	5.798
27.0	.8917	7.425	72.0	.6931	5.769
28.0	.8861	7.378	73.0	.6897	5.741
29.0	.8805	7.332	74.0	.6863	5.712
30.0	.8750	7.286	75.0	.6829	5.685
31.0	.8696	7.241	76.0	.6796	5.657
32.0	.8642	7.196	77.0	.6763	5.629
33.0	.8589	7.152	78.0	.6731	5.602
34.0	.8537	7.108	79.0	.6699	5.576
35.0	.8485	7.065	80.0	.6667	5.549
36.0	.8434	7.022	81.0	.6635	5.522
37.0	.8383	6.980	82.0	.6604	5.497
38.0	.8333	6.939	83.0	.6573	5.471
39.0	.8284	6.898	84.0	.6542	5.445
40.0	.8235	6.857	85.0	.6512	5.420
41.0	.8187	6.817	86.0	.6482	5.395
42.0	.8140	6.777	87.0	.6452	5.370
43.0	.8092	6.738	88.0	.6422	5.345
44.0	.8046	6.699	89.0	.6393	5.320
45.0	.8000	6.661	90.0	.6364	5.296
46.0	.7955	6.623	91.0	.6335	5.272
47.0	.7910	6.586	92.0	.6306	5.248
48.0	.7865	6.548	93.0	.6278	5.225
49.0	.7821	6.511	94.0	.6250	5.201
50.0	.7778	6.476	95.0	.6222	5.178
51.0	.7735	6.440	96.0	.6195	5.155
52.0	.7692	6.404	97.0	.6167	5.132
53.0	.7650	6.369	98.0	.6140	5.110
54.0	.7609	6.334	99.0	.6114	5.088
55.0	.7568	6.300	100.0	.6087	5.066

(See Circular No. 57, Bureau of Standards, for more complete tables.)

Table 144—TEMPERATURE CORRECTIONS TO READINGS OF BAUME HYDROMETERS*

American Petroleum Oils at Various Temperatures
(Standard at 60 Deg. Fahr.; modulus 140.)

Observed Temperature Deg. Fahr.	OBSERVED DEGREES BAUME.							
	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
	ADD TO OBSERVED DEGREES BAUME.							
30	1.7	2.0	2.4	3.0	3.7	4.3	5.0	5.7
32	1.6	1.9	2.3	2.8	3.4	4.0	4.7	5.3
34	1.5	1.8	2.1	2.6	3.1	3.7	4.3	4.9
36	1.4	1.6	2.0	2.4	2.9	3.4	4.0	4.6
38	1.3	1.5	1.8	2.2	2.6	3.1	3.6	4.2
40	1.2	1.4	1.6	2.0	2.4	2.8	3.2	3.8
42	1.1	1.2	1.5	1.8	2.2	2.5	2.9	3.4
44	.9	1.1	1.3	1.6	2.0	2.2	2.6	3.0
46	.8	.9	1.1	1.4	1.7	1.9	2.3	2.7
48	.7	.8	.9	1.2	1.4	1.6	2.0	2.3
50	.6	.7	.8	1.0	1.2	1.4	1.6	1.9
52	.5	.6	.7	.8	1.0	1.1	1.3	1.5
54	.3	.4	.5	.6	.8	.9	1.0	1.1
56	.2	.3	.3	.4	.5	.6	.6	.7
58	.1	.1	.1	.2	.3	.3	.3	.4
	SUBTRACT FROM OBSERVED DEGREES BAUME.							
60	.0	.0	.0	.0	.0	.0	.0	.0
62	.1	.1	.1	.2	.2	.3	.3	.4
64	.2	.3	.3	.4	.4	.6	.6	.7
66	.3	.4	.5	.6	.7	.8	.9	1.0
68	.5	.6	.6	.7	.9	1.1	1.3	1.4
70	.6	.7	.8	.9	1.1	1.4	1.6	1.7
72	.7	.8	.9	1.1	1.3	1.6	1.9	2.1
74	.8	.9	1.1	1.3	1.6	1.8	2.2	2.5
76	.9	1.1	1.3	1.5	1.8	2.1	2.5	2.8
78	1.0	1.2	1.4	1.7	2.0	2.4	2.8	3.1
80	1.1	1.3	1.5	1.8	2.2	2.6	3.1	3.5
82	1.2	1.4	1.7	2.0	2.5	2.9	3.4	3.9
84	1.3	1.5	1.8	2.2	2.7	3.2	3.7	4.3
86	1.4	1.7	2.0	2.4	2.9	3.4	4.0	4.6
88	1.6	1.8	2.1	2.6	3.1	3.7	4.2	4.9
90	1.7	2.0	2.3	2.7	3.3	3.9	4.5	5.2
92	1.8	2.1	2.4	2.9	3.5	4.2	4.8	5.6
94	1.9	2.2	2.6	3.1	3.8	4.4	5.1	5.9
96	2.0	2.3	2.7	3.3	4.0	4.6	5.4	6.3
98	2.1	2.4	2.9	3.4	4.2	4.9	5.7	6.6
100	2.2	2.6	3.0	3.6	4.4	5.1	6.0	6.9
102	2.3	2.7	3.2	3.8	4.6	5.4	6.3	7.2
104	2.4	2.9	3.3	4.0	4.8	5.7	6.6	7.5
106	2.5	3.0	3.5	4.2	5.0	5.9	6.9	7.9
108	2.7	3.1	3.6	4.3	5.2	6.2	7.2	8.2
110	2.8	3.2	3.7	4.4	5.4	6.4	7.5	8.5
112	2.9	3.3	3.9	4.6	5.6	6.7	7.7	8.8
114	3.0	3.4	4.0	4.7	5.8	6.9	7.9	9.1
116	3.1	3.6	4.1	4.9	6.0	7.1	8.2	9.4
118	3.2	3.7	4.3	5.1	6.2	7.3	8.5	9.8
120	3.3	3.8	4.4	5.3	6.4	7.5	8.8	10.1

* (Circular No. 57, Bureau of Standards.)

Centigrade and Fahrenheit Scales—Thermometry is the art of measuring temperatures. The term "thermometer" is derived from the Greek words "therme" (heat) and "metron" (measure), meaning therefore, "heat measure." This interpretation, however, should not be employed literally, for thermometers do not measure heat, but, rather the degree or density of heat.

In 1714 Gabriel Daniel Fahrenheit (1676-1736) conceived the idea of using mercury (quicksilver) as the indicating liquid in thermometers. He constructed such a thermometer and proceeded to graduate it, calling "body temperature" 24, and the freezing and boiling points of water 8 and 53, respectively. Fahrenheit considered the unit of temperature too large. Retaining his original zero as the datum point he divided each division of the scale into 4; accordingly the freezing point of water became 32 degrees and the boiling point 212 degrees.

The Centigrade or Celsius thermometric scale was originated by Anders Celsius (1701-1744) in 1741. He called the point to which the mercury fell when immersed in melting ice, zero, and the boiling point of water 100, and divided the interval between these points into 100 equal divisions.

Comparing the Fahrenheit and Centigrade scales we note that 180 fahr. degrees equals 100 cent. degrees, or 1 cent. degree equals nine-fifths degrees. This relation exists over the entire scale. To convert Centigrade into Fahrenheit degrees, however, we cannot simply multiply the former by nine-fifths, for we note that the zero or starting point of the scales are not coincident; consequently, a correction of 32 (the difference between the two scales at the melting point of ice) must be made.

The following formulae are used to convert one temperature reading into the other.

Cent. degrees $=$ (fahr. degrees—32) $\times 5/9$

Fahr. degrees $=$ (cent. degrees $\times 9/5) + 32$

Table 145—CENTIGRADE TO FAHRENHEIT

deg. cent.	0	1	2	3	4	5	6	7	8	9	deg. cent.	0	1	2	3	4	5	6	7	8	9
—40	—40	—42	—44	—45	—47	—49	—51	—53	—54	—56	230	446	448	450	451	453	455	457	459	460	462
—30	—22	—24	—26	—27	—29	—31	—33	—35	—36	—38	240	464	466	468	469	471	473	475	477	478	480
—20	— 4	— 6	— 8	— 9	—11	—13	—15	—17	—18	—20	250	482	484	486	487	489	491	493	495	496	498
—10	14	12	10	9	7	5	3	+ 1	0	— 2	260	500	502	504	505	507	509	511	513	514	516
— 0	32	30	28	27	25	23	21	19	18	16	270	518	520	522	523	525	527	529	531	532	534
0	32	34	36	37	39	41	43	45	46	48	280	536	538	540	541	543	545	547	549	550	552
10	50	52	54	56	57	59	61	63	64	66	290	554	556	558	559	561	563	565	567	568	570
20	68	70	72	73	75	77	78	81	82	84	300	572	574	576	577	579	581	583	585	586	588
30	86	88	90	91	93	95	97	99	100	102	310	590	592	594	595	597	599	601	603	604	606
40	104	106	108	109	111	113	115	117	118	120	320	608	610	612	613	615	617	619	621	622	624
50	122	124	126	127	129	131	133	135	136	138	330	626	628	630	631	633	635	637	639	640	642
60	140	142	143	145	147	149	151	153	154	156	340	644	646	648	649	651	653	655	657	658	660
70	158	160	162	163	165	167	169	171	172	174	350	662	664	666	667	669	671	673	675	676	678
80	176	178	180	181	183	185	187	189	190	192	360	680	682	684	685	687	689	691	693	694	696
90	194	196	198	199	201	203	205	207	208	210	370	698	700	702	703	705	707	709	711	712	714
100	212	214	216	217	219	221	223	225	226	228	380	716	718	720	721	723	725	727	729	730	732
110	230	232	234	235	237	239	241	243	244	246	390	734	736	738	739	741	743	745	747	748	750
120	248	250	252	253	255	257	259	261	262	264	400	752	754	756	757	759	761	763	765	766	768
130	266	268	270	271	273	275	277	279	280	282	410	770	772	774	775	777	779	781	783	784	786
140	284	286	288	289	291	293	295	297	298	300	420	788	790	792	793	795	797	799	801	802	804
150	302	304	306	307	309	311	313	315	316	318	430	806	808	810	811	813	815	817	819	820	822
160	320	322	324	325	327	329	331	333	334	336	440	824	826	828	829	831	833	835	837	838	840
170	338	340	342	343	345	347	349	351	352	354	450	842	844	846	847	849	851	853	855	856	858
180	356	358	360	361	363	365	367	369	370	372	460	860	862	864	865	867	869	871	873	874	876
190	374	376	378	379	381	383	385	387	388	390	470	878	880	882	883	885	887	889	891	892	894
200	392	394	396	397	399	401	403	405	406	408	480	896	898	900	901	903	905	907	909	910	912
210	410	412	414	415	417	419	421	423	424	426	490	914	916	918	919	921	923	925	927	928	930
220	428	430	432	433	435	437	439	441	442	444	500	932	934	936	937	939	941	944	945	946	948

Table 146—AREAS

	Sq. in. to sq. cm.	Sq. cm. to sq. in.	Sq. ft. to sq. m.	Sq. m. to sq. ft.	Sq. yd. to Sq. m.	Sq. m. to sq. yd.	Acres to Hectares	Hectares to Acres	Sq. mi. to Sq. km.	Sq. km. to sq. mi.
1	6.452	0.1550	0.0929	10.76	0.8361	1.196	0.4047	2.471	2.590	0.3861
2	12.90	0.3100	0.1858	21.53	1.672	2.392	0.8094	4.942	5.180	0.7722
3	19.35	0.4650	0.2787	32.29	2.508	3.588	1.214	7.413	7.770	1.158
4	25.81	0.6200	0.3716	43.06	3.345	4.784	1.619	9.884	10.360	1.544
5	32.26	0.7750	0.4645	53.82	4.181	5.980	2.023	12.355	12.950	1.931
6	38.71	0.9300	0.5574	64.58	5.017	7.176	2.428	14.826	15.540	2.317
7	45.16	1.085	0.6503	75.35	5.853	8.372	2.833	17.297	18.130	2.703
8	51.61	1.240	0.7432	86.11	6.689	9.568	3.237	19.768	20.720	3.089
9	58.06	1.395	0.8361	96.87	7.525	10.764	3.642	22.239	23.310	3.475

Table 147—VOLUMES OR CUBIC MEASURE

	Cu. in. to cu. cm.	Cu. cm. to cu. in.	Cu. ft. to cu. m.	Cu. m. to cu. ft.	Cu. yd. to cu. m.	Cu. m. to cu. yd.	Gallons to cu. ft.	Cu. ft. to gallons
1	16.39	0.06102	0.02832	35.31	0.7646	1.308	0.1337	7.481
2	32.77	0.1220	0.05663	70.63	1.529	2.616	0.2674	14.96
3	49.16	0.1831	0.08495	105.9	2.294	3.924	0.4011	22.44
4	65.55	0.2441	0.1133	141.3	3.058	5.232	0.5348	29.92
5	81.94	0.3051	0.1416	176.6	3.823	6.540	0.6685	37.41
6	98.32	0.3661	0.1699	211.9	4.587	7.848	0.8022	44.89
7	114.7	0.4272	0.1982	247.2	5.352	9.156	0.9359	52.36
8	131.1	0.4882	0.2265	282.5	6.116	10.46	1.070	59.85
9	147.5	0.5492	0.2549	317.8	6.881	11.77	1.203	67.33

Table 148—VOLUMES OR CAPACITIES

	Liquid Ounces to cu. cm.	Cu. cm. to liquid ounces	Pints to liters	Liters to pints	Quarts to liters	Liters to quarts	Gallons to liters	Liters to gallons	Bushels to Hectoliters	Hectoliters to bushels
1	29.57	0.03381	0.4732	2.113	0.9464	1.057	3.785	0.2642	0.3524	2.838
2	59.15	0.06763	0.9464	4.227	1.893	2.113	7.571	0.5283	0.7048	5.676
3	88.72	0.1014	1.420	6.340	2.839	3.170	11.36	0.7925	1.057	8.513
4	118.3	0.1353	1.893	8.453	3.785	4.227	15.14	1.057	1.410	11.35
5	147.9	0.1691	2.366	10.57	4.732	5.283	18.93	1.321	1.762	14.19
6	177.4	0.2029	2.839	12.68	5.678	6.340	22.71	1.585	2.114	17.03
7	207.0	0.2367	3.312	14.79	6.625	7.397	26.50	1.849	2.467	19.86
8	236.6	0.2705	3.785	16.91	7.571	8.453	30.28	2.113	2.819	22.70
9	266.2	0.3043	4.259	19.02	8.517	9.510	34.07	2.378	3.172	25.54

Table 149—MASSES

	Grains to grams	Grams to grains	Ounces (avoir.) to grams	Grams to ounces (avoir.)	Pounds (avoir.) to kilograms	Kilograms to pounds (avoir.)	Short tons (2000 lb.) to metric tons	Metric tons (1000 kg.) to short tons	Long tons (2240 lb.) to metric tons	Metric tons to long tons
1	0.06480	15.43	28.35	0.03527	0.4536	2.205	0.907	1.102	1.016	0.984
2	0.1296	30.86	56.70	0.07055	0.9072	4.409	1.814	2.205	2.032	1.968
3	0.1944	46.30	85.05	0.1058	1.361	6.614	2.722	3.307	3.048	2.953
4	0.2592	61.73	113.40	0.1411	1.814	8.818	3.629	4.409	4.064	3.937
5	0.3240	77.16	141.75	0.1764	2.268	11.02	4.536	5.512	5.080	4.921
6	0.3888	92.59	170.10	0.2116	2.722	13.23	5.443	6.614	6.096	5.905
7	0.4536	108.03	198.45	0.2469	3.175	15.43	6.350	7.716	7.112	6.889
8	0.5184	123.46	226.80	0.2822	3.629	17.64	7.257	8.818	8.128	7.874
9	0.5832	138.89	255.15	0.3175	4.082	19.84	8.165	9.921	9.144	8.857

Table 150—MEASURES

	Liquid Ounces to Cu. Cm.	Cu. Cm. to Liquid. Ounces	Pints to Liters	Liters to Pints	Quarts to Liters	Liters to Quarts	Amer. Gals. to Liters	Liters to Amer.Gals.
1	29.57	0.03381	0.4732	2.113	0.9464	1.057	3.785	0.2642
2	59.15	0.06763	0.9464	4.227	1.893	2.113	7.571	0.5283
3	88.72	0.1014	1.420	6.340	2.839	3.170	11.36	0.7925
4	118.3	0.1353	1.893	8.453	3.785	4.227	15.14	1.057
5	147.9	0.1691	2.366	10.57	4.732	5.283	18.93	1.321
6	177.4	0.2029	2.839	12.68	5.678	6.340	22.71	1.585
7	207.0	0.2367	3.312	14.79	6.625	7.397	26.50	1.849
8	236.6	0.2705	3.785	16.91	7.571	8.453	30.28	2.113
9	266.2	0.3043	4.259	19.02	8.517	9.510	34.07	2.378

Table 151—WEIGHTS

Short Tons 2000 lb. to Metric Tons	Metric Tons 1000 kg. to Short Tons		Long Tons 2240 lb. to Metric Tons	Metric Tons to Long Tons
0.907	1.102	1	1.016	0.984
1.814	2.205	2	2.032	1.968
2.722	3.307	3	3.048	2.953
3.629	4.409	4	4.064	3.937
4.536	5.512	5	5.080	4.921
5.443	6.614	6	6.096	5.905
6.350	7.716	7	7.112	6.889
7.257	8.818	8	8.128	7.874
8.165	9.921	9	9.144	8.857

Table 152—MEASURES

AMERICAN GALLONS

Gallons	Imp. Gallons	Cubic Feet	Cubic Metre	Litres
1	.8325438	.1336806	.003785401	3.784796
2	1.6650876	.2673611	.007570802	7.569592
3	2.4976314	.4010417	.011356203	11.354388
4	3.3301752	.5347222	.01541604	15.139184
5	4.1627190	.6684028	.018927005	18.923980
6	4.9952628	.8020833	.022712406	22.708776
7	5.8278066	.9357639	.026497807	26.493572
8	6.6603504	1.0694444	.030283208	30.278368
9	7.4928942	1.2031250	.03468609	34.063164

IMPERIAL GALLONS

Gallons	Amer. Gallons	Cubic Feet	Cubic Metre	Litres
1	1.201138	.1605688	.00454669	4.5459631
2	2.402276	.3211376	.00909338	9.0919262
3	3.603414	.4817064	.01364007	13.6378893
4	4.804552	.6422752	.01818676	18.1838524
5	6.005690	.8028440	.02273345	22.7298155
6	7.206828	.9634128	.02728014	27.2757786
7	8.407966	1.1239816	.03182683	31.8217417
8	9.609104	1.2845504	.03637352	36.3677048
9	10.810242	1.4451192	.04092021	40.9136679

LITRES

Litres	Amer. Gallons	Imp. Gallons	Cubic Feet	Cubic Metre
1	.264215	.21997539	.03532041	.00100016
2	.528430	.43995078	.07064082	.00200032
3	.792645	.65992617	.10596123	.00300048
4	1.056860	.87990156	.14128164	.00400064
5	1.321075	1.09987695	.17660205	.00500080
6	1.585290	1.31985234	.21192246	.00600096
7	1.849505	1.53982773	.24724287	.00700112
8	2.113720	1.75980312	.28256328	.00800128
9	2.377935	1.97977851	.31788369	.00900144

TANK MEASUREMENTS*

D = Diameter. C = Circumference.

U. S. gal. = United States gal. of 231 cubic inches.

IMP. gal. = Imperial gal. of 277.274 cubic inches.

D in inches squared × 0.0034 = U. S. gal. per inch.

D in inches squared × 0.00283257 = Imp. gal. per inch.

D in feet squared × 0.011656 = 42 U. S. gal. bbls. per inch.

C in feet squared ÷ 20.1586 = U. S. gal. per inch.

C in feet squared × 0.04960677 = U. S. gal. per inch.

C in feet squared × 0.00118111 = 42 U. S. gal. bbls. per inch.

C in feet squared × 0.00099213 = 50 U. S. gal. bbls. per inch.

C in feet squared × 0.041327896 = Imp. gal. per inch.

Imp. gal. ÷ 1.20032 = U. S. gal.

U. S. gal. × 0.83311 = Imp. gal.

C of Circle = D × 3.14159.

D of Circle = C × 0.3183.

Area of Circle = $D^2 \times 0.7854$, also $C^2 \times 0.07958$.

To find internal circumference of tank, deduct from external circumference in feet 0.033 of a foot for each one sixteenth of an inch thickness of iron and use internal circumference in making table.

What is the capacity per inch of a tank 92 inches in diameter?

Opposite 92 in column "Diameter in Inches" read 28.778 United States gal.; 23.975 Imperial gal.; 0.685 bbls. of 42 gal., etc.

What is capacity per inch of a tank 92.5 inches in diameter?

Opposite 92, as above, read .... 28.778 U. S. gal.

Difference between 92 and 93 is 0.629

One half .... 0.3145 U. S. gal.

92.5 = 29.0925

* Courtesy of the Phoenix Refining Co.

Table 153—VERTICAL TANKS

Capacity per inch of depth

Gallons per Inch		Diameter in Inches	Barrels per Inch	
Imperial	U. S.		42 U. S. gal.	50 U. S. gal.
3.671	4.406	36	.105	.088
3.878	4.655	37	.111	.093
4.090	4.910	38	.117	.098
4.308	5.171	39	.123	.103
4.532	5.440	40	.130	.109
4.762	5.715	41	.136	.114
4.997	5.998	42	.143	.120
5.237	6.287	43	.150	.126
5.484	6.582	44	.157	.132
5.736	6.885	45	.164	.138
5.994	7.194	46	.171	.144
6.257	7.511	47	.179	.150
6.526	7.834	48	.187	.157
6.801	8.163	49	.194	.163
7.081	8.500	50	.202	.170
7.368	8.843	51	.211	.177
7.659	9.194	52	.219	.184
7.957	9.551	53	.227	.191
8.259	9.914	54	.236	.198
8.569	10.285	55	.245	.206
8.883	10.662	56	.254	.213
9.203	11.047	57	.263	.221
9.529	11.438	58	.272	.229
9.860	11.835	59	.282	.237
10.197	12.240	60	.291	.245
10.540	12.651	61	.301	.253
10.888	13.070	62	.311	.261
11.242	13.495	63	.321	.270
11.602	13.926	64	.332	.279
11.968	14.365	65	.342	.287
12.339	14.810	66	.353	.296
12.715	15.263	67	.363	.305
13.098	15.722	68	.374	.314
13.486	16.187	69	.385	.324
13.880	16.660	70	.397	.333
14.279	17.139	71	.408	.343
14.684	17.626	72	.420	.353
15.094	18.119	73	.431	.362
15.511	18.618	74	.443	.372
15.933	19.125	75	.455	.383
16.361	19.638	76	.468	.393
16.794	20.159	77	.480	.403
17.233	20.686	78	.493	.414
17.678	21.219	79	.505	.424
18.128	21.760	80	.518	.435

Table 154—VERTICAL TANKS

Capacity per inch of depth

Gallons per Inch		Diameter in Inches	Barrels per Inch	
Imperial	U. S.		42 U. S. gal.	50 U. S. gal.
18.584	22.307	81	.531	.446
19.046	22.862	82	.544	.457
19.514	23.423	83	.558	.468
19.986	23.990	84	.571	.480
20.465	24.565	85	.585	.491
20.950	25.146	86	.599	.503
21.440	25.735	87	.613	.515
21.935	26.330	88	.627	.526
22.437	26.931	89	.641	.539
22.944	27.540	90	.656	.551
23.457	28.155	91	.670	.563
23.975	28.778	92	.685	.575
24.499	29.407	93	.700	.588
25.029	30.042	94	.715	.601
25.564	30.685	95	.731	.614
26.105	31.334	96	.746	.627
26.652	31.991	97	.762	.640
27.204	32.654	98	.777	.653
27.762	33.324	99	.793	.666
28.326	34.000	100	.810	.680
28.895	34.683	101	.826	.694
29.470	35.374	102	.842	.707
30.051	36.071	103	.859	.721
30.637	36.774	104	.876	.735
31.229	37.485	105	.892	.750
31.827	38.202	106	.910	.764
32.430	38.927	107	.927	.778
33.039	39.658	108	.944	.793
33.654	40.395	109	.962	.808
34.274	41.140	110	.980	.823
34.900	41.891	111	.997	.838
35.532	42.645	112	1.015	.853
36.169	43.415	113	1.034	.868
36.812	44.186	114	1.052	.884
37.461	44.965	115	1.071	.899
38.115	45.750	116	1.089	.915
38.775	46.543	117	1.108	.931
39.441	47.342	118	1.127	.947
40.112	48.147	119	1.146	.963
40.789	48.960	120	1.166	.979
41.472	49.779	121	1.185	.995
42.160	50.606	122	1.205	1.012
42.854	51.439	123	1.225	1.029
43.554	52.278	124	1.244	1.045
44.259	53.125	125	1.265	1.062

Table 155—VERTICAL TANKS

Capacity per inch of depth

Gallons per Inch		Diameter in Inches	Barrels per Inch	
Imperial	U. S.		42 U. S. gal.	50 U. S. gal.
44.970	53.978	126	1.285	1.079
45.687	54.839	127	1.306	1.097
46.409	55.706	128	1.326	1.114
47.137	56.579	129	1.347	1.131
47.870	57.460	130	1.368	1.149
48.610	58.347	131	1.389	1.167
49.355	59.242	132	1.411	1.185
50.105	60.143	133	1.432	1.203
50.862	61.050	134	1.454	1.221
51.624	61.965	135	1.475	1.239
52.391	62.886	136	1.497	1.258
53.165	63.815	137	1.520	1.276
53.943	64.750	138	1.542	1.295
54.728	65.691	139	1.564	1.314
55.518	66.640	140	1.587	1.333
56.314	67.595	141	1.609	1.352
57.116	68.558	142	1.632	1.371
57.923	69.527	143	1.656	1.390
58.736	70.502	144	1.679	1.410
59.555	71.485	145	1.702	1.430
60.379	72.474	146	1.726	1.449
61.209	73.471	147	1.749	1.469
62.045	74.474	148	1.773	1.489
62.886	75.483	149	1.797	1.510
63.733	76.500	150	1.822	1.530
64.585	77.523	151	1.846	1.550
65.444	78.554	152	1.870	1.571
66.308	79.591	153	1.895	1.592
67.177	80.634	154	1.920	1.613
68.052	81.685	155	1.945	1.634
68.933	82.742	156	1.970	1.655
69.820	83.807	157	1.995	1.676
70.712	84.878	158	2.021	1.697
71.610	85.955	159	2.047	1.719
72.514	87.040	160	2.072	1.741
73.423	88.131	161	2.098	1.763
74.338	89.230	162	2.124	1.784
75.259	90.335	163	2.151	1.807
76.185	91.446	164	2.177	1.829
77.117	92.565	165	2.204	1.851
78.054	93.690	166	2.231	1.874
78.998	94.823	167	2.258	1.896
79.946	95.962	168	2.285	1.919
80.901	97.107	169	2.312	1.942
81.861	98.260	170	2.340	1.965

Table 156—VERTICAL TANKS

Capacity per inch of depth

Gallons per Inch		Diameter in Inches	Barrels per Inch	
Imperial	U. S.		42 U. S. gal.	50 U. S. gal.
82.827	99.419	171	2.367	1.988
83.799	100.586	172	2.395	2.012
84.776	101.759	173	2.423	2.035
85.759	102.939	174	2.451	2.059
86.747	104.125	175	2.479	2.082
87.452	105.318	176	2.508	2.106
88.742	106.519	177	2.536	2.130
89.747	107.726	178	2.565	2.154
90.758	108.939	179	2.594	2.179
91.775	110.160	180	2.623	2.203
92.798	111.387	181	2.652	2.228
93.826	112.622	182	2.681	2.252
94.860	113.863	183	2.711	2.277
95.899	115.110	184	2.741	2.302
96.945	116.365	185	2.771	2.327
97.996	117.626	186	2.801	2.352
99.052	118.895	187	2.831	2.378
100.114	120.107	188	2.861	2.403
101.182	121.451	189	2.892	2.429
102.256	122.740	190	2.922	2.454
103.335	124.035	191	2.953	2.481
104.420	125.338	192	2.984	2.507
105.510	126.647	193	3.016	2.533
106.607	127.962	194	3.047	2.559
107.708	129.285	195	3.078	2.586
108.816	130.614	196	3.110	2.612
109.929	131.951	197	3.142	2.639
111.048	133.294	198	3.174	2.666
112.173	134.643	199	3.206	2.693
113.303	136.000	200	3.238	2.720
114.439	137.363	201	3.271	2.747
115.580	138.734	202	3.303	2.775
116.727	140.111	203	3.336	2.802
117.880	141.494	204	3.369	2.830
119.039	142.885	205	3.402	2.858
120.203	144.282	206	3.447	2.896
121.373	145.686	207	3.469	2.914
122.548	147.098	208	3.502	2.942
123.729	148.515	209	3.536	2.970
124.916	149.940	210	3.569	2.999
126.109	151.370	211	3.604	3.027
127.307	152.810	212	3.638	3.056
128.511	154.255	213	3.673	3.085
129.720	155.706	214	3.707	3.114
130.936	157.165	215	3.742	3.143

Table—157 VERTICAL TANKS

Capacity per inch of depth

Gallons per Inch		Diameter in Inches	Barrels per Inch	
Imperial	U. S.		42 U. S. gal.	50 U. S. gal.
132.156	158.630	216	3.777	3.173
133.383	160.103	217	3.812	3.202
134.615	161.582	218	3.847	3.232
135.853	163.067	219	3.882	3.261
137.096	164.560	220	3.918	3.291
138.346	166.059	221	3.954	3.321
139.600	167.566	222	3.990	3.351
140.861	169.079	223	4.026	3.381
142.127	170.598	224	4.062	3.412
143.399	172.125	225	4.098	3.442
144.676	173.658	226	4.135	3.473
145.959	175.199	227	4.172	3.504
147.248	176.746	228	4.209	3.535
148.543	178.299	229	4.246	3.566
149.843	179.860	230	4.283	3.597
151.149	181.427	231	4.320	3.628
152.460	183.002	232	4.357	3.660
153.777	184.583	233	4.395	3.692
155.100	186.170	234	4.433	3.723
156.429	187.765	235	4.471	3.755
157.763	189.366	236	4.509	3.787
159.103	190.975	237	4.547	3.819
160.448	192.590	238	4.586	3.852
161.799	194.211	239	4.624	3.884
163.156	195.840	240	4.663	3.917
164.518	197.475	241	4.702	3.949
165.887	199.118	242	4.741	3.982
167.260	200.767	243	4.781	4.015
168.640	202.422	244	4.820	4.048
170.025	204.085	245	4.859	4.082
171.416	205.754	246	4.899	4.115
172.812	207.431	247	4.939	4.149
174.214	209.114	248	4.979	4.182
175.622	210.803	249	5.020	4.216
177.036	212.500	250	5.060	4.250
178.455	214.203	251	5.100	4.284
179.879	215.914	252	5.141	4.318
181.310	217.631	253	5.182	4.353
182.746	219.354	254	5.223	4.387
184.188	221.085	255	5.264	4.422
185.635	222.822	256	5.306	4.456
187.088	224.567	257	5.347	4.491
188.547	226.318	258	5.389	4.526
190.012	228.075	259	5.431	4.561
191.482	229.840	260	5.473	4.597

Table 158—VERTICAL TANKS

Capacity per inch of depth

Gallons per Inch		Diameter in Inches	Barrels per Inch	
Imperial	U. S.		42 U. S. gal.	50 U. S. gal.
192.958	231.611	261	5.515	4.632
194.439	233.390	262	5.557	4.668
195.926	235.175	263	5.600	4.703
197.419	236.966	264	5.643	4.739
198.917	238.765	265	5.686	4.775
200.421	240.570	266	5.729	4.811
201.931	242.383	267	5.772	4.848
203.447	244.202	268	5.815	4.884
204.968	246.027	269	5.858	4.920
206.494	247.860	270	5.902	4.957
208.027	249.699	271	5.946	4.994
209.565	251.546	272	5.990	5.031
211.108	253.399	273	6.034	5.068
212.658	255.258	274	6.078	5.105
214.213	257.125	275	6.123	5.142
215.774	258.998	276	6.168	5.180
217.340	260.879	277	6.212	5.217
218.912	262.766	278	6.257	5.255
220.490	264.659	279	6.302	5.293
222.073	266.560	280	6.348	5.331
223.663	268.467	281	6.392	5.369
225.257	270.382	282	6.438	5.408
226.858	272.303	283	6.484	5.446
228.464	274.230	284	6.530	5.485
230.075	276.165	285	6.576	5.523
231.693	278.106	286	6.622	5.562
233.316	280.055	287	6.669	5.601
234.945	282.010	288	6.715	5.640
236.579	283.971	289	6.762	5.679
238.219	285.940	290	6.809	5.719
239.865	287.915	291	6.856	5.758
241.516	289.898	292	6.903	5.798
243.173	291.887	293	6.951	5.838
244.836	293.882	294	6.999	5.878
246.504	295.885	295	7.046	5.918
248.178	297.894	296	7.094	5.958
249.858	299.911	297	7.141	5.998
251.544	301.934	298	7.190	6.039
352.235	303.963	299	7.238	6.079
254.931	306.000	300	7.286	6.120
256.634	308.043	301	7.335	6.161
258.342	310.094	302	7.384	6.202
260.055	312.151	303	7.433	6.243
261.775	314.214	304	7.482	6.284
263.500	316.285	305	7.532	6.326

Table 159—VERTICAL TANKS

Capacity per inch of depth

Gallons per Inch		Diameter in Inches	Barrels per Inch	
Imperial	U. S.		42 U. S. gal.	50 U. S. gal.
265.231	318.362	306	7.581	6.367
266.967	320.447	307	7.630	6.409
268.709	322.538	308	7.680	6.451
270.457	324.635	309	7.730	6.493
272.210	326.740	310	7.780	6.535
273.969	328.851	311	7.830	6.577
275.734	330.970	312	7.881	6.619
277.504	333.095	313	7.932	6.662
279.280	335.226	314	7.982	6.704
281.062	337.365	315	8.032	6.747
282.849	339.510	316	8.083	6.790
284.642	341.663	317	8.135	6.833
286.441	343.822	318	8.187	6.876
288.245	345.987	319	8.239	6.920
290.055	348.160	320	8.290	6.963
291.871	350.339	321	8.342	7.007
293.692	352.526	322	8.393	7.050
295.519	354.719	323	8.446	7.094
297.352	356.918	324	8.498	7.138
299.190	359.125	325	8.550	7.182
301.034	361.338	326	8.604	7.227
302.884	363.559	327	8.657	7.271
304.739	365.786	328	8.710	7.316
306.600	368.019	329	8.763	7.360
308.467	370.260	330	8.816	7.405
310.339	372.507	331	8.870	7.450
312.217	374.762	332	8.924	7.495
314.101	377.023	333	8.977	7.540
315.990	379.290	334	9.032	7.586
317.885	381.565	335	9.086	7.631
319.786	383.846	336	9.140	7.677
321.692	386.135	337	9.195	7.723
323.604	388.430	338	9.248	7.768
325.522	390.731	339	9.304	7.815
327.445	393.040	340	9.360	7.861
329.374	395.355	341	9.414	7.907
331.309	397.678	342	9.469	7.953
333.249	400.007	343	9.525	8.000
335.195	402.342	344	9.580	8.047
337.147	404.687	345	9.636	8.094
339.104	407.036	346	9.693	8.141
341.067	409.393	347	9.748	8.188
343.036	411.756	348	9.805	8.235
345.010	414.125	349	9.861	8.282
346.990	416.500	350	9.918	8.330

Table 160—VERTICAL TANKS

Capacity per inch of depth

Gallons per Inch		Diameter in Inches	Barrels per Inch	
Imperial	U. S.		42 U. S. gal.	50 U. S. gal.
348.975	418.883	351	9.975	8.378
350.967	421.274	352	10.032	8.425
352.964	423.671	353	10.088	8.473
354.966	426.074	354	10.146	8.521
356.975	428.485	355	10.203	8.570
358.989	430.902	356	10.260	8.618
361.008	433.327	357	10.317	8.666
363.034	435.758	358	10.376	8.715
365.064	438.195	359	10.434	8.764
367.101	440.640	360	10.491	8.813

HORIZONTAL TANKS

The following tables give capacities in U. S. gal. of tanks from 36 to 120 inches in diameter and one inch in length.

To obtain capacity at a given inch, multiply figures in tables by length of tank in inches. See page 601.

EXAMPLE—Tank 200 inches long, 36 inches in diameter; what is capacity at 15 inches?

Under column "36 inches in diameter" and opposite 15 inches read 1.739. $1.739 \times 200 = 347.800$ U. S. gal. at 15 inches.

The upper half of a horizontal tank being the same as the lower half, the tables are figured for one half diameter of tank. The following shows a simple method of making tables.

The capacity opposite 18.5 (table for diameter 37 inches) being omitted when putting table on regular gauge blank, a difference of 16 (twice the difference 8) being shown as the difference between 18 and 19.

When the internal diameter is not even inches, it will be found near enough for practical purposes to make a table to the nearest inch as follows:

Tank 36.25 inches diameter and 100 inches long.

Total capacity of tank = 446.8 U. S. gal. Divide this by capacity of tank 36 inches diameter and one inch long (4.406 U. S. gal.) Use result (101.407) as length of tank in making tables. This divides the actual capacity into 36 inches instead of 36.25 inches, and will be found accurate enough for most purposes.

When necessary to make table in Imp. gal., multiply length by 0.83311 and use result as length in making table.

When tanks have curved ends (similar to those on tank cars) add to length of shell = of each bilge for length of tank.

If tank is more than half full and it is desired to ascertain amount of oil in tank, proceed as follows:

Example—Length = 300 inches.
Diameter = 60 inches.
Height of oil = 45 inches.
Capacity of tank if full............3672 U. S. gal.
60—45 = 15 in. space; capacity
at 15 in.........................717.6 U. S. gal.
Amount in tank..................2954.4 U. S. gal.

Fig. 165

Horizontal Tank, Diameter 36 inches. Length 100 inches

Inch	Capacity to Nearest Gallon	Difference	Capacity of Upper Half	Inch
18	220	15	235	19
17	205	16	251	20
16	189	15	266	21
15	174	15	281	22
14	159	16	297	23
13	143	14	311	24
12	129	15	326	25
11	114	14	340	26
10	100	14	354	27
9	86	13	367	28
8	73	13	380	29
7	60	12	392	30
6	48	11	403	31
5	37	10	413	32
4	27	9	422	33
3	18	8	430	34
2	10	7	437	35
1	3	3	440	36

Horizontal Tank, Diameter 37 inches. Length 100 inches

Inch	Capacity to Nearest Gallon	Difference	Capacity of Upper Half	Inch
18.5	233	8	241	19
18	225	16	257	20
17	209	16	273	21
16	193	16	289	22
15	177	16	305	23
14	161	15	320	24
13	146	15	335	25
12	131	15	350	26
11	116	14	364	27
10	102	14	378	28
9	88	14	392	29
8	74	13	405	30
7	61	12	417	31
6	49	11	428	32
5	38	11	439	33
4	27	9	448	34
3	18	8	456	35
2	10	6	462	36
1	4	4	466	37

Table 161—HORIZONTAL TANKS

Multiply capacity in tables by length of tank in inches.

Diam. 36 In.	Diam. 37 In.	Diam. 38 In.	Inch	Diam. 39 In.	Diam. 40 In.	Diam. 41 In.
			20.5			2.858
			20		2.720	2.769
			19.5	2.586		
		2.445	19	2.501	2.547	2.591
	2.327		18.5			
2.203	2.247	2.290	18	2.332	2.374	2.415
2.047	2.087	2.126	17	2.165	2.202	2.239
1.893	1.928	1.963	16	1.998	2.032	2.065
1.739	1.770	1.801	15	1.832	1.863	1.894
1.585	1.613	1.643	14	1.669	1.697	1.724
1.434	1.459	1.484	13	1.509	1.533	1.557
1.286	1.308	1.330	12	1.351	1.372	1.393
1.140	1.159	1.179	11	1.198	1.216	1.233
.999	1.015	1.032	10	1.047	1.063	1.079
.861	.875	.889	9	.903	.916	.929
.729	.740	.752	8	.763	.774	.785
.603	.612	.621	7	.631	.639	.648
.483	.490	.497	6	.505	.512	.518
.371	.376	.382	5	.387	.392	.398
.268	.271	.275	4	.280	.283	.287
.175	.178	.180	3	.183	.185	.188
.096	.098	.099	2	.100	.102	.103
.034	.035	.035	1	.036	.036	.037

Diam. 42 In.	Diam. 43 In.	Diam. 44 In.	Inch	Diam. 45 In.	Diam. 46 In.	Diam. 47 In.
			23.5			3.755
			23		3.597	3.653
			22.5	3.442		
		3.291	22	3.344	3.397	3.450
	3.143		21.5			
2.998	3.050	3.100	21	3.149	3.199	3.248
2.817	2.864	2.908	20	2.955	3.002	3.047
2.636	2.679	2.721	19	2.763	2.805	2.846
2.455	2.495	2.533	18	2.572	2.609	2.647
2.276	2.313	2.347	17	2.381	2.416	2.450
2.098	2.132	2.163	16	2.193	2.225	2.256
1.922	1.952	1.981	15	2.009	2.037	2.064
1.750	1.776	1.802	14	1.827	1.852	1.876
1.580	1.603	1.626	13	1.648	1.672	1.693
1.414	1.434	1.454	12	1.473	1.494	1.513
1.252	1.269	1.287	11	1.304	1.321	1.338
1.094	1.110	1.125	10	1.139	1.154	1.168
.942	.955	.968	9	.980	.993	1.005
.797	.807	.817	8	.827	.838	.848
.657	.666	.675	7	.682	.691	.699
.526	.532	.540	6	.546	.552	.558
.403	.408	.414	5	.418	.424	.428
.291	.294	.297	4	.301	.304	.308
.190	.193	.194	3	.197	.199	.200
.104	.106	.107	2	.108	.110	.111
.037	.038	.038	1	.038	.039	.039

Table 162—HORIZONTAL TANKS

Multiply capacity in tables by length of tank in inches.

Diam. 48 In.	Diam 49 In.	Diam. 50 In.	Inch	Diam. 51 In.	Diam. 52 In.	Diam. 53 In.
			26.5			4.776
			26		4.597	4.660
			25.5	4.422		
		4.250	25	4.309	4.371	4.431
	4.082		24.5			
3.917	3.975	4.033	24	4.085	4.146	4.203
3.707	3.765	3.817	23	3.865	3.922	3.976
3.498	3.555	3.602	22	3.647	3.700	3.749
3.289	3.345	3.388	21	3.431	3.479	3.523
3.084	3.136	3.175	20	3.216	3.259	3.300
2.881	2.928	2.964	19	3.002	3.044	3.078
2.679	2.722	2.755	18	2.790	2.825	2.859
2.478	2.517	2.548	17	2.580	2.613	2.644
2.281	2.316	2.344	16	2.374	2.405	2.432
2.087	2.118	2.145	15	2.170	2.199	2.222
1.900	1.924	1.948	14	1.971	1.996	2.016
1.716	1.734	1.756	13	1.777	1.797	1.815
1.533	1.550	1.569	12	1.585	1.605	1.622
1.353	1.370	1.386	11	1.402	1.417	1.433
1.180	1.195	1.210	10	1.223	1.235	1.251
1.017	1.027	1.040	9	1.052	1.063	1.077
.859	.866	.878	8	.888	.897	.907
.708	.716	.723	7	.729	.737	.746
.565	.575	.578	6	.583	.587	.595
.432	.440	.442	5	.447	.451	.454
.310	.317	.319	4	.319	.326	.329
.201	.205	.208	3	.211	.214	.214
.113	.114	.114	2	.114	.117	.119
.040	.041	.041	1	.041	.041	.042

Diam. 54 In.	Diam. 55 In.	Diam. 56 In.	Inch	Diam. 57 In.	Diam. 58 In.	Diam. 59 In.
			29.5			5.918
			29		5.719	5.790
			28.5	5.523		
		5.331	28	5.399	5.467	5.535
	5.143		27.5			
4.957	5.023	5.089	27	5.153	5.217	5.280
4.723	4.785	4.847	26	4.907	4.967	5.026
4.490	4.547	4.605	25	4.662	4.717	4.773
4.258	4.311	4.365	24	4.417	4.469	4.521
4.026	4.076	4.125	23	4.175	4.223	4.271
3.794	3.842	3.886	22	3.934	3.978	4.023
3.566	3.611	3.651	21	3.694	3.736	3.777
3.340	3.381	3.418	20	3.456	3.495	3.534
3.116	3.152	3.188	19	3.222	3.256	3.293
2.893	2.926	2.959	18	2.992	3.020	3.057
2.674	2.704	2.734	17	2.766	2.788	2.823
2.459	2.486	2.513	16	2.543	2.563	2.594
2.248	2.271	2.296	15	2.321	2.344	2.369
2.041	2.061	2.084	14	2.104	2.128	2.149
1.838	1.857	1.876	13	1.895	1.916	1.934

Table 163—HORIZONTAL TANKS

Multiply capacity in tables by length of tank in inches.

Diam. 54 In.	Diam. 55 In.	Diam, 56 In.	Inch	Diam. 57 In.	Diam. 58 In.	Diam. 59 In.
1.640	1.657	1.675	12	1.692	1.710	1.726
1.449	1.464	1.478	11	1.495	1.509	1.524
1.265	1.279	1.290	10	1.304	1.316	1.329
1.086	1.099	1.108	9	1.120	1.130	1.141
.915	.926	.936	8	.943	.953	.961
.755	.759	.769	7	.776	.784	.791
.602	.607	.614	6	.620	.626	.631
.461	.466	.470	5	.473	.479	.483
.331	.335	.337	4	.340	.344	.347
.217	.219	.220	3	.223	.225	.227
.119	.120	.121	2	.122	.123	.124
.042	.042	.043	1	.043	.044	.044

Diam. 60 In.	Diam. 61 In.	Diam. 62 In.	Inch	Diam. 63 In.	Diam. 64 In.	Diam. 65 In.
			32.5			7.182
			32		6.963	7.039
			31.5	6.747		
		6.535	31	6.610	6.686	6.755
	6.326		30.5			
6.119	6.193	6.267	30	6.337	6.410	6.472
5.858	5.929	5.999	29	6.065	6.134	6.193
5.598	5.668	5.732	28	5.794	5.858	5.915
5.339	5.407	5.465	27	5.523	5.584	5.639
5.082	5.146	5.199	26	5.254	5.310	5.363
4.826	4.885	4.935	25	4.986	5.038	5.089
4.572	4.625	4.672	24	4.722	4.769	4.817
4.318	4.366	4.412	23	4.458	4.503	4.547
4.066	4.111	4.153	22	4.196	4.239	4.281
3.818	3.859	3.898	21	3.937	.3.976	4.016
3.572	3.609	3.645	20	3.683	3.718	3.756
3.328	3.363	3.397	19	3.430	3.464	3.496
3.088	3.120	3.151	18	3.181	3.213	3.242
2.852	2.881	2.910	17	2.937	2.964	2.992
2.621	2.646	2.672	16	2.698	2.723	2.748
2.392	2.417	2.440	15	2.463	2.486	2.508
2.171	2.192	2.213	14	2.232	2.254	2.274
1.954	1.972	1.991	13	2.008	2.027	2.045
1.743	1.759	1.776	12	1.791	1.808	1.823
1.538	1.552	1.567	11	1.581	1.595	1.608
1.341	1.352	1.366	10	1.378	1.390	1.401
1.152	1.161	1.173	9	1.183	1.192	1.203
.971	.980	.988	8	.996	1.005	1.013
.799	.806	.812	7	.819	.827	.833
.634	.642	.648	6	.653	.659	.664
.487	.491	.496	5	.500	.504	.508
.349	.354	.357	4	.359	.362	.365
.229	.230	.233	3	.235	.238	.238
.125	.126	.128	2	.128	.129	.131
.C45	.045	.045	1	.046	.046	.047

Table 164—HORIZONTAL TANKS

Multiply capacity in tables by length of tank in inches.

Diam. 66 In.	Diam. 67 In.	Diam. 68 In.	Inch	Diam. 69 In.	Diam. 70 In.	Diam. 71 In.
			35.5			8.570
			35		8.330	8.413
			34.5	8.094		
		7.861	34	7.944	8.026	8.107
	7.631		33.5			
7.406	7.485	7.567	33	7.646	7.723	7.801
7.120	7.194	7.273	32	7.348	7.421	7.495
6.834	6.904	6.979	31	7.051	7.120	7.190
6.549	6.617	6.687	30	6.755	6.819	6.886
6.264	6.327	6.395	29	6.459	6.519	6.583
5.981	6.041	6.104	28	6.164	6.222	6.283
5.699	5.756	5.814	27	5.870	5.927	5.983
5.419	5.473	5.528	26	5.580	5.634	5.686
5.141	5.191	5.244	25	5.292	5.343	5.391
4.865	4.913	4.961	24	5.006	5.052	5.098
4.592	4.637	4.681	23	4.724	4.764	4.809
4.322	4.363	4.403	22	4.444	4.481	4.524
4.504	4.092	4.129	21	4.167	4.204	4.241
3.789	3.824	3.859	20	3.893	3.929	3.962
3.529	3.561	4.593	19	3.625	3.657	3.688
3.273	3.302	3.331	18	3.360	3.388	3.418
3.020	3.046	3.074	17	3.101	3.125	3.152
2.772	2.797	2.821	16	2.846	2.868	2.894
2.530	2.553	2.575	15	2.595	2.617	2.640
2.294	2.314	2.333	14	2.352	2.372	2.391
2.064	2.080	2.099	13	2.116	2.135	2.150
1.839	1.855	1.871	12	1.886	1.901	1.916
1.622	1.636	1.650	11	1.663	1.674	1.693
1.413	1.426	1.439	10	1.449	1.459	1.476
1.213	1.223	1.235	9	1.242	1.254	1.264
1.022	1.030	1.041	8	1.047	1.060	1.063
.841	.847	.855	7	.859	.871	.874
.670	.675	.680	6	.687	.689	.697
.512	.516	.520	5	.524	.528	.531
.368	.371	.374	4	.377	.378	.382
.240	.243	.244	3	.246	.249	.250
.131	.132	.133	2	.134	.135	.136
.047	.047	.047	1	.048	.048	.048

Table 165—HORIZONTAL TANKS

Multiply capacity in tables by length of tank in inches.

Diam. 72 In.	Diam. 73 In.	Diam. 74 In.	Inch	Diam. 75 In.	Diam. 76 In.	Diam. 77 In
			38.5			10.079
			38		9.819	9.912
			37.5	9.562		
		9.309	37	9.400	9.489	9.579
	9.059		36.5			
8.813	8.899	8.989	36	9.076	9.160	9.246
8.500	8.582	8.669	35	8.752	8.832	8.914
8.188	8.267	8.349	34	8.428	8.505	8.583
7.877	7.953	8.030	33	8.104	8.178	8.253
7.567	7.639	7.712	32	7.782	7.852	7.924
7.259	7.326	7.395	31	7.461	7.528	7.596
6.952	7.015	7.080	30	7.142	7.205	7.268
6.645	6.706	6.766	29	6.824	6.886	6.944
6.341	6.397	6.454	28	6.509	6.567	6.622
6.038	6.091	6.145	27	6.195	6.250	6.302
5.736	5.786	5.839	26	5.885	5.938	5.988
5.439	5.485	5.535	25	5.578	5.628	5.675
5.144	5.188	5.232	24	5.274	5.300	5.364
4.852	4.892	4.934	23	4.975	5.014	5.056
4.563	4.599	4.639	22	4.677	4.715	4.753
4.278	4.311	4.374	21	4.383	4.418	4.453
3.997	4.025	4.062	20	4.094	4.127	4.161
3.719	3.748	3.781	19	3.809	3.839	3.871
3.446	3.474	3.501	18	3.529	3.556	3.585
3.179	3.204	3.229	17	3.255	3.280	3.305
2.917	2.938	2.962	16	2.985	3.008	3.032
2.658	2.681	2.702	15	2.723	2.744	2.764
2.408	2.429	2.447	14	2.467	2.485	2.503
1.167	2.184	2.200	13	2.216	2.234	2.250
1.932	1.946	1.960	12	1.978	1.990	2.003
1.703	1.716	1.727	11	1.742	1.753	1.767
1.483	1.494	1.505	10	1.515	1.527	1.538
1.272	1.281	1.291	9	1.300	1.309	1.318
1.071	1.079	1.086	8	1.095	1.102	1.110
.880	.887	.893	7	.899	.906	.912
.701	.707	.712	6	.717	.722	.727
.536	.540	.544	5	.548	.551	.555
.386	.388	.391	4	.393	.396	.399
.252	.253	.254	3	.256	.259	.260
.138	.138	.139	2	.140	.141	.142
.048	.049	.049	1	.050	.050	.050

Table 166—HORIZONTAL TANKS

Multiply capacity in tables by length of tank in inches.

Diam. 78 In.	Diam. 79 In.	Diam. 80 In.	Inch	Diam. 81 In.	Diam. 82 In.	Diam. 83 In.
			41.5			11.711
			41		11.431	11.531
			40.5	11.154		
		10.880	40	10.978	11.075	11.172
	10.610		39.5			
10.343	10.439	10.533	39	10.627	10.720	10.814
10.004	10.097	10.187	38	10.277	10.365	10.456
9.666	9.756	9.841	37	9.927	10.012	10.098
9.329	9.416	9.496	36	9.578	9.659	9.741
8.994	9.076	9.151	35	9.231	9.307	9.385
8.659	8.737	8.809	34	8.884	8.957	9.031
8.325	8.398	8.468	33	8.538	8.608	8.679
7.992	8.060	8.128	32	8.194	8.260	8.328
7.660	7.724	7.789	31	7.854	7.916	7.980
7.330	7.391	7.454	30	7.514	7.575	7.633
7.001	7.059	7.120	29	7.176	7.234	7.286
6.676	6.734	6.788	28	6.842	6.893	6.947
6.354	6.407	6.458	27	6.509	6.557	6.610
6.035	6.085	6.132	26	6.181	6.228	6.274
5.719	5.764	5.809	25	5.853	5.899	5.943
5.406	5.449	5.490	24	5.532	5.574	5.615
5.096	5.138	5.175	23	5.212	5.252	5.291
4.791	4.829	4.864	22	4.900	4.933	4.970
4.487	4.523	4.557	21	4.592	4.624	4.657
4.189	4.224	4.254	20	4.286	4.316	4.346
3.897	3.928	3.956	19	3.987	4.013	4.043
3.610	3.637	3.665	18	3.691	3.717	3.742
3.329	3.355	3.377	17	3.403	3.426	3.450
3.053	3.076	3.098	16	3.120	3.141	3.164
2.784	2.804	2.825	15	2.846	2.863	2.883
2.522	2.540	2.558	14	2.576	2.592	2.612
2.267	2.282	2.299	13	2.315	2.329	2.345
2.019	2.033	2.047	12	2.062	2.074	2.089
1.779	1.791	1.804	11	1.816	1.827	1.840
1.548	1.560	1.570	10	1.582	1.591	1.606
1.328	1.336	1.345	9	1.355	1.365	1.372
1.118	1.126	1.132	8	1.141	1.148	1.156
.919	.924	.931	7	.937	.943	.950
.731	.736	.742	6	.746	.752	.757
.559	.563	.565	5	.569	.574	.576
.401	.404	.407	4	.409	.412	.415
.261	.264	.265	3	.267	.269	.269
.143	.143	.145	2	.146	.147	.148
.051	.051	.051	1	.052	.052	.053

Table 167—HORIZONTAL TANKS

Multiply capacity in tables by length of tank in inches.

Diam. 84 In.	Diam. 85 In.	Diam. 86 In.	Inch	Diam. 87 In.	Diam. 88 In.	Diam. 89 In.
			44.5			3.466
			44		13.165	13.273
			43.5	12.867		
		12.573	43	12.679	12.783	12.887
	12.283		42.5			
11.995	12.099	12.201	42	12.303	12.401	12.501
11.632	11.731	11.829	41	11.927	12.019	12.116
11.269	11.363	11.457	40	11.552	11.638	11.734
10.906	10.997	11.086	39	11.177	11.261	11.352
10.544	10.632	10.716	38	10.802	10.884	10.970
10.183	10.267	10.347	37	10.430	10.508	10.589
9.822	9.903	9.979	36	10.058	10.132	10.209
9.462	9.540	9.611	35	9.687	9.759	9.832
9.104	9.177	9.245	34	9.318	9.387	9.458
8.747	8.816	8.883	33	8.951	9.018	9.085
8.392	8.459	8.523	32	8.587	8.651	8.713
8.040	8.105	8.164	31	8.226	8.287	8.345
7.690	7.751	7.807	30	7.865	7.925	7.978
7.344	7.401	7.454	29	7.509	7.566	7.617
7.000	7.054	7.104	28	7.156	7.210	7.258
6.658	6.710	6.756	27	6.805	6.856	6.901
6.320	6.369	6.413	26	6.458	6.504	6.549
5.986	6.030	6.074	25	6.118	6.158	6.201
5.656	5.699	5.738	24	5.773	5.816	5.858
5.330	5.368	5.404	23	5.445	5.482	5.516
5.007	5.043	5.078	22	5.114	5.150	5.182
4.690	4.724	4.756	21	4.790	4.821	4.855
4.378	4.410	4.440	20	4.469	4.499	4.528
4.071	4.098	4.126	19	4.155	4.181	4.211
3.770	3.796	3.821	18	3.847	3.872	3.896
3.475	3.497	3.522	17	3.544	3.576	3.590
3.186	3.206	3.227	16	3.249	3.269	3.291
2.904	2.924	2.941	15	2.961	2.980	2.999
2.629	2.646	2.663	14	2.679	2.699	2.714
2.362	2.378	2.393	13	2.406	2.421	2.439
2.104	2.116	2.129	12	2.142	2.154	2.169
1.853	1.865	1.876	11	1.888	1.900	1.912
1.613	1.621	1.633	10	1.641	1.656	1.663
1.383	1.391	1.400	9	1.407	1.416	1.425
1.162	1.169	1.176	8	1.185	1.190	1.200
.954	.962	.967	7	.973	.979	.983
.760	.765	.770	6	.776	.778	.784
.580	.585	.587	5	.592	.595	.598
.417	.420	.422	4	.429	.429	.430
.272	.274	.275	3	.278	.279	.280
.148	.149	.151	2	.151	.153	.154
.053	.053	.053	1	.054	.055	.055

Table 168—HORIZONTAL TANKS

Multiply capacity in tables by length of tank in inches.

Diam. 90 In.	Diam. 91 In.	Diam. 92 In.	Inch	Diam. 93 In.	Diam. 94 In.	Diam. 95 In.
			47.5			15.342
			47		15.021	15.136
			46.5	14.703		
		14.388	46	14.501	14.612	14.726
	14.078		45.5			
13.770	13.880	13.988	45	14.098	14.207	14.316
13.378	13.487	13.590	44	13.696	13.802	13.905
12.987	13.094	13.194	43	13.296	13.397	13.495
12.597	12.701	12.798	42	12.896	12.993	13.086
12.209	12.308	12.403	41	12.497	12.590	12.679
11.822	11.915	12.008	40	12.098	12.187	12.273
11.436	11.525	11.613	39	11.699	11.785	11.867
11.051	11.137	11.218	38	11.301	11.384	11.463
10.667	10.750	10.826	37	10.906	10.983	11.061
10.284	10.363	10.438	36	10.513	10.587	10.662
9.903	9.977	10.050	35	10.123	10.193	10.265
9.524	9.596	9.665	34	9.733	9.800	9.870
9.184	9.216	9.281	33	9.344	9.410	9.476
8.773	8.837	8.900	32	8.962	9.024	9.084
8.403	8.463	8.523	31	8.580	8.639	8.697
8.035	8.093	8.149	30	8.200	8.257	8.313
7.670	7.724	7.777	29	7.827	7.880	7.932
7.308	7.358	7.409	28	7.456	7.506	7.553
6.948	6.996	7.046	27	7.089	7.138	7.182
6.593	6.638	6.687	26	6.727	6.771	6.812
6.242	6.283	6.331	25	6.367	6.407	6.450
5.894	5.934	5.976	24	6.013	6.052	6.090
5.552	5.588	5.626	23	5.662	5.700	5.734
5.215	5.248	5.284	22	5.320	5.352	5.386
4.883	4.916	4.948	21	4.979	5.010	5.042
4.656	4.587	4.617	20	4.647	4.673	4.701
4.235	4.264	4.292	19	4.317	4.343	4.368
3.921	3.946	3.972	18	3.996	4.021	4.045
3.611	3.635	3.657	17	3.681	3.703	3.727
3.309	3.331	3.353	16	3.375	3.393	3.414
3.014	3.035	3.056	15	3.073	3.091	3.109
2.729	2.747	2.763	14	2.781	2.796	2.814
2.452	2.468	2.480	13	2.497	2.510	2.524
2.183	2.196	2.210	12	2.222	2.232	2.248
1.922	1.934	1.946	11	1.957	1.966	1.981
1.673	1.682	1.696	10	1.703	1.714	1.723
1.433	1.443	1.455	9	1.459	1.469	1.474
1.204	1.214	1.216	8	1.226	1.232	1.240
.989	.995	1.000	7	1.007	1.010	1.019
.787	.793	.799	6	.803	.807	.812
.601	.605	.608	5	.613	.616	.618
.432	.435	.440	4	.440	.445	.445
.281	.284	.290	3	.290	.291	.292
.154	.155	.156	2	.157	.158	.160
.055	.055	.056	1	.056	.065	.056

Table 169—HORIZONTAL TANKS

Multiply capacity in tables by length of tank in inches.

Diam. 96 In.	Diam. 97 In.	Diam. 98 In.	Inch	Diam. 99 In.	Diam. 100 In.	Diam. 101 In.
			50.5			17.342
			50		17.000	17.122
			49.5	16.662		
		16.327	49	16.446	16.565	16.683
	15.995		48.5			
15.668	15.785	15.898	48	16.016	16.132	16.247
15.248	15.365	15.473	47	15.587	15.699	15.812
14.828	14.945	15.049	46	15.159	15.267	15.377
14.410	14.525	14.626	45	14.732	14.837	14.942
13.992	14.108	14.205	44	14.305	14.407	14.507
13.574	13.692	13.784	43	13.880	13.978	14.073
13.158	13.276	13.363	42	13.458	13.551	13.642
12.744	12.860	12.944	41	13.036	13.125	13.213
12.336	12.446	12.527	40	12.615	12.700	12.784
11.930	12.033	12.111	39	12.197	12.277	12.356
11.524	11.622	11.698	38	11.780	11.855	11.931
11.119	11.214	11.287	37	11.365	11.436	11.508
10.716	10.807	10.877	36	10.952	11.020	11.090
10.315	10.400	10.468	35	10.539	10.605	10.672
9.915	9.997	10.063	34	10.128	10.194	10.257
9.518	9.599	9.661	33	9.723	9.785	9.846
9.124	9.204	9.263	32	9.322	9.379	9.437
8.736	8.810	8.867	31	8.921	8.977	9.032
8.352	8.420	8.473	30	8.526	8.578	8.630
7.974	8.035	8.085	29	8.136	8.184	8.233
7.600	7.654	7.700	28	7.747	7.793	7.840
7.230	7.274	7.318	27	7.362	7.407	7.450
6.862	6.897	6.940	26	6.982	7.024	7.065
6.494	6.526	6.569	25	6.607	6.647	6.685
6.128	6.163	6.203	24	6.239	6.274	6.311
5.770	5.803	5.841	23	5.874	5.908	5.942
5.416	5.450	5.484	22	5.514	5.546	5.579
5.066	5.101	5.131	21	5.160	5.190	5.221
4.726	4.757	4.786	20	4.814	4.841	4.868
4.394	4.421	4.449	19	4.472	4.498	4.523
4.068	4.092	4.116	18	4.138	4.162	4.185
3.752	3.770	3.792	17	3.811	3.833	3.855
3.444	3.455	3.472	16	3.491	3.511	3.531
3.139	3.145	3.160	15	3.181	3.198	3.215
2.838	2.844	2.856	14	2.878	2.893	2.908
2.546	2.554	2.565	13	2.583	2.597	2.612
2.260	2.273	2.282	12	2.298	2.311	2.324
1.990	2.001	2.016	11	2.025	2.035	2.041
1.728	1.742	1.754	10	1.759	1.769	1.779
1.480	1.492	1.501	9	1.508	1.516	1.524
1.240	1.254	1.260	8	1.266	1.274	1.282
1.016	1.032	1.035	7	1.040	1.046	1.053
.804	.821	.823	6	.828	.833	.838
.620	.625	.628	5	.633	.636	.640
.447	.448	.453	4	.453	.456	.458
.292	.293	.295	3	.297	.297	.298
.160	.160	.162	2	.162	.162	.162
.056	.057	.058	1	.058	.058	.058

Table 170—HORIZONTAL TANKS

Multiply capacity in tables by length of tank in inches.

Diam. 102 In.	Diam. 103 In.	Diam. 104 In.	Inch	Diam. 105 In.	Diam. 106 In.	Diam. 107 In.
			53.5			19.463
			53		19.101	19.230
			52.5	18.742		
		18.387	52	18.513	18.639	18.776
	18.035		51.5			
17.687	17.811	17.936	51	18.057	18.180	18.303
17.246	17.364	17.485	50	17.603	17.723	17.841
16.805	16.918	17.035	49	17.150	17.266	17.381
16.364	16.473	16.587	48	16.697	16.810	16.922
15.924	16.030	16.140	47	16.245	16.354	16.463
15.485	15.587	15.693	46	15.794	15.898	16.004
15.047	15.144	15.247	45	15.343	15.444	15.545
14.609	14.701	14.802	44	14.893	14.991	15.087
14.172	14.259	14.357	43	14.447	14.539	14.629
13.738	13.819	13.912	42	14.002	14.089	14.176
13.304	13.384	13.470	41	13.558	13.642	13.724
12.871	12.950	13.032	40	13.116	13.196	13.275
12.440	12.516	12.597	39	12.675	12.752	12.828
12.011	12.083	12.164	38	12.237	12.310	12.384
11.587	11.655	11.732	37	11.802	11.869	11.943
11.163	11.229	11.297	36	11.371	11.434	11.503
10.743	10.805	10.872	35	10.940	11.005	11.069
10.325	10.386	10.450	34	10.511	10.576	10.635
9.911	9.968	10.029	33	10.088	10.150	10.205
9.498	9.556	9.610	32	9.666	9.725	9.779
9.087	9.147	9.198	31	9.249	9.303	9.354
8.680	8.738	8.789	30	8.837	8.888	8.937
8.282	8.331	8.382	29	8.430	8.474	8.523
7.884	7.930	7.978	28	8.025	8.069	8.116
7.497	7.537	7.582	27	7.623	7.668	7.710
7.108	7.148	7.190	26	7.229	7.272	7.312
6.722	6.764	6.804	25	6.841	6.877	6.919
6.340	6.387	6.423	24	6.457	6.491	6.526
5.972	6.010	6.046	23	6.076	6.111	6.143
5.608	5.644	5.671	22	5.704	5.733	5.767
5.251	5.281	5.308	21	5.336	5.366	5.395
4.895	4.924	4.950	20	4.978	5.005	5.029
4.549	4.576	4.599	19	4.626	4.648	4.673
4.208	4.230	4.255	18	4.277	4.300	4.323
3.877	3.896	3.920	17	3.938	3.960	3.980
3.554	3.568	3.588	16	3.608	3.626	3.643
3.235	3.250	3.267	15	3.285	3.302	3.320
2.916	2.938	2.955	14	2.971	2.988	3.001
2.622	2.639	2.653	13	2.667	2.680	2.696
2.333	2.348	2.361	12	2.373	2.384	2.398
2.056	2.069	2.080	11	2.090	2.101	2.110
1.787	1.798	1.809	10	1.814	1.824	1.834
1.531	1.542	1.548	9	1.556	1.564	1.571
1.278	1.295	1.300	8	1.308	1.314	1.320
1.057	1.064	1.068	7	1.074	1.077	1.084
.845	.844	.850	6	.853	.858	.862
.642	.646	.649	5	.652	.655	.658
.458	.462	.467	4	.469	.470	.473
.300	.301	.302	3	.304	.306	.306
.163	.164	.164	2	.165	.166	.167
.058	.059	.059	1	.059	.059	.060

Table 171—HORIZONTAL TANKS

Multiply capacity in tables by length of tank in inches.

Inch	Diam. 108 In.	Diam. 109 In.	Diam. 110 In.	Inch	Diam. 111 In.	Diam. 112 In.
				56		21.325
55			20.570	55.5	20.946	
54.5		20.198		55	20.703	20.837
54	19.828	19.962	20.093	54	20.219	20.349
53	19.359	19.490	19.616	53	19.738	19.863
52	18.892	19.019	19.140	52	19.259	19.379
51	18.426	18.548	18.664	51	18.781	18.897
50	17.961	18.077	18.188	50	18.305	18.415
49	17.496	17.607	17.715	49	17.829	17.936
48	17.031	17.137	17.244	48	17.353	17.457
47	16.567	16.670	16.774	47	16.877	16.980
46	16.103	16.203	16.304	46	16.403	16.503
45	15.639	15.737	15.836	45	15.932	16.028
44	15.178	15.272	15.368	44	15.461	15.554
43	14.719	14.810	14.905	43	14.992	15.080
42	14.263	14.349	14.444	42	14.523	14.610
41	13.810	13.890	13.983	41	14.064	14.141
40	13.359	13.435	13.524	40	13.589	13.672
39	12.910	12.983	13.066	39	13.130	13.210
38	12.464	12.531	12.608	38	12.676	12.751
37	12.019	12.083	12.155	37	12.223	12.292
36	11.576	11.639	11.704	36	11.772	11.838
35	11.135	11.197	11.258	35	11.323	11.388
34	11.698	10.758	10.816	34	10.879	10.942
33	10.265	10.322	10.378	33	10.437	10.497
32	9.836	9.892	9.944	32	10.002	10.055
31	9.412	9.463	9.514	31	9.570	9.620
30	8.992	9.037	9.087	30	9.141	9.188
29	8.576	8.619	8.664	29	8.714	8.761
28	8.165	8.207	8.244	28	8.290	8.338
27	7.756	7.796	7.833	27	7.878	7.919
26	7.352	7.391	7.428	26	7.468	7.507
25	6.953	6.993	7.026	25	7.063	7.101
24	6.560	6.597	6.628	24	6.665	6.703
23	6.176	6.209	6.238	23	6.274	6.307
22	5.797	5.827	5.856	22	5.888	5.916
21	5.428	5.453	5.481	21	5.509	5.536
20	5.059	5.084	5.116	20	5.136	5.163
19	4.696	4.720	4.754	19	4.771	4.795
18	4.343	4.367	4.396	18	4.413	4.434
17	4.000	4.022	4.046	17	4.059	4.081
16	3.661	3.682	3.704	16	3.718	3.738
15	3.335	3.353	3.366	15	3.385	3.402
14	3.020	3.032	3.036	14	3.062	3.077
13	2.711	2.723	2.724	13	2.748	2.764
12	2.409	2.422	2.428	12	2.445	2.457
11	2.121	2.131	2.140	11	2.153	2.162
10	1.843	1.852	1.864	10	1.870	1.881
9	1.575	1.586	1.599	9	1.600	1.610
8	1.323	1.336	1.347	8	1.347	1.350
7	1.085	1.095	1.102	7	1.106	1.111
6	.868	.871	.876	6	.880	.885
5	.662	.665	.671	5	.671	.674
4	.476	.477	.479	4	.480	.482
3	.309	.309	.310	3	.312	.314
2	.169	.170	.170	2	.170	.171
1	.060	.060	.060	1	.061	.061

Table 172—HORIZONTAL TANKS

Multiply capacity in tables by length of tank in inches.

Inch	Diam. 113 In.	Diam. 114 In.	Inch	Diam. 115 In.	Diam. 116 In.
			58		22.875
57		22.093	57.5	22.482	
56.5	21.707		57	22.230	22.371
56	21.461	21.599	56	21.733	21.868
55	20.971	21.105	55	21.236	21.366
54	20.481	20.611	54	20.740	20.865
53	19.991	20.117	53	20.244	20.365
52	19.504	19.624	52	19.748	19.866
51	19.017	19.132	51	19.252	19.368
50	18.530	18.643	50	18.756	18.870
49	18.044	18.155	49	18.262	18.373
48	17.559	17.668	48	17.772	17.877
47	17.074	17.181	47	17.282	17.382
46	16.590	16.695	46	16.795	16.888
45	16.112	16.212	45	16.309	16.398
44	15.638	15.731	44	15.823	15.911
43	15.165	15.253	43	15.341	15.427
42	14.692	14.775	42	14.862	14.944
41	14.221	14.299	41	14.383	14.462
40	13.751	13.828	40	13.906	13.981
39	13.283	13.360	39	13.431	13.501
38	12.821	12.893	38	12.964	13.023
37	12.361	12.428	37	12.497	12.549
36	11.904	11.967	36	12.033	12.079
35	11.449	11.511	35	11.572	11.613
34	10.999	11.057	34	11.116	11.152
33	10.552	10.609	33	10.664	10.697
32	10.108	10.165	32	10.217	10.250
31	9.669	9.722	31	9.771	9.812
30	9.235	9.288	30	9.331	9.377
29	8.805	8.856	29	8.898	8.944
28	8.383	8.425	28	8.468	8.513
27	7.962	8.003	27	8.040	8.086
26	7.548	7.583	26	7.622	7.663
25	7.139	7.176	25	7.213	7.247
24	6.736	6.770	24	6.806	6.838
23	6.339	6.369	23	6.401	6.434
22	5.948	5.978	22	6.007	6.036
21	5.560	5.592	21	5.619	5.645
20	5.188	5.212	20	5.238	5.262
19	4.817	4.841	19	4.865	4.888
18	4.457	4.476	18	4.499	4.519
17	4.101	4.120	17	4.139	4.160
16	3.755	3.771	16	3.786	3.813
15	3.419	3.436	15	3.451	3.468
14	3.091	3.109	14	3.121	3.136
13	2.772	2.786	13	2.799	2.813
12	2.468	2.481	12	2.491	2.502
11	2.171	2.183	11	2.192	2.201
10	1.887	1.898	10	1.907	1.914
9	1.615	1.624	9	1.632	1.639
8	1.357	1.365	8	1.371	1.376
7	1.113	1.120	7	1.126	1.131
6	.886	.890	6	.895	.899
5	.675	.681	5	.684	.686
4	.486	.488	4	.490	.492
3	.317	.317	3	.319	.320
2	.171	.172	2	.173	.175
1	.062	.062	1	.062	.062

Table 173—HORIZONTAL TANKS

Multiply capacity in tables by length of tank in inches.

Inch	Diam. 117 In.	Diam. 118 In.	Inch	Diam. 119 In.	Diam. 120 In.
			60		24.479
59		23.671	59.5	24.074	
58.5	23.271		59	23.816	23.954
58	23.016	23.160	58	23.301	23.434
57	22.506	22.649	57	22.787	22.914
56	21.998	22.138	56	22.273	22.395
55	21.493	21.627	55	21.760	21.877
54	20.989	21.117	54	21.247	21.359
53	20.485	20.609	53	20.734	20.842
52	19.992	20.102	52	20.221	20.328
51	19.479	19.597	51	19.710	19.815
50	18.977	19.092	50	19.203	19.305
49	18.476	18.587	49	18.697	18.795
48	17.975	18.083	48	18.191	18.287
47	17.478	17.582	47	17.685	17.780
46	16.984	17.082	46	17.182	17.273
45	16.491	16.584	45	16.681	16.767
44	15.999	16.088	44	16.180	16.265
43	15.510	15.595	43	15.682	15.768
42	15.024	15.105	42	15.188	15.273
41	14.540	14.620	41	14.697	14.779
40	14.056	14.137	40	14.209	14.287
39	13.578	13.654	39	13.725	13.797
38	13.102	13.174	38	13.245	13.314
37	12.632	12.698	37	12.767	12.833
36	12.162	12.225	36	12.291	12.354
35	11.698	11.758	35	11.818	11.881
34	11.238	11.292	34	11.350	11.411
33	10.778	10.832	33	10.888	10.944
32	10.323	10.377	32	10.429	10.483
31	9.872	9.924	31	9.975	10.024
30	9.428	9.476	30	9.524	9.567
29	8.988	9.031	29	9.082	9.124
28	8.555	8.595	28	8.643	8.683
27	8.125	8.165	27	8.207	8.244
26	7.701	7.739	26	7.779	7.816
25	7.282	7.319	25	7.357	7.393
24	6.870	6.905	24	6.940	6.976
23	6.460	6.496	23	6.529	6.561
22	6.065	6.094	22	6.127	6.153
21	5.675	5.702	21	5.730	5.751
20	5.292	5.317	20	5.342	5.363
19	4.913	4.937	19	4.959	4.981
18	4.541	4.562	18	4.587	4.608
17	4.179	4.197	17	4.220	4.240
16	3.826	3.845	16	3.867	3.882
15	3.483	3.501	15	3.520	3.538
14	3.149	3.163	14	3.180	3.198
13	2.828	2.841	13	2.853	2.866
12	2.516	2.526	12	2.535	2.537
11	2.215	2.223	11	2.232	2.239
10	1.925	1.932	10	1.938	1.949
9	1.645	1.655	9	1.659	1.668
8	1.385	1.390	8	1.396	1.396
7	1.136	1.141	7	1.146	1.151
6	.903	.909	6	.910	.915
5	.689	.694	5	.696	.699
4	.496	.497	4	.498	.501
3	.321	.322	3	.325	.326
2	.175	.175	2	.178	.178
1	.063	.063	1	.063	.063

Table 174—PRESSURE EQUIVALENTS

Ounces	In. Water	In. Mercury	In. Mer. cury	Ounces	In. Water	In. Water	In. Mercury	Ounces
.25	.43	.032	1.	7.85	13.60	.25	.018	.144
.50	.87	.064	1.5	11.78	20.40	.50	.037	.259
.75	1.30	.095	2.	15.71	27.20	.75	.055	.433
1.	1.73	.127	2.5	1.23 lb.	34.00	1.	.073	.577
2.	3.46	.26	3.	1.47 "	40.80	2.	.147	1.15
3.	5.19	.38	3.5	1.72 "	47.60	3.	.22	1.73
4.	6.92	.51	4.	1.96 "	54.40	4.	.29	2.31
5.	8.65	.64	4.5	2.21 "	61.20	5.	.37	2.89
6.	10.38	.77	5.	2.45 "	68.00	6.	.44	3.46
7.	12.11	.89	5.5	2.71 "	74.80	7.	.51	4.04
8.	13.85	1.02	6.	2.94 "	81.60	8.	.59	4.62
9.	15.58	1.15	6.5	3.19 "	88.40	9.	.66	5.20
10.	17.31	1.27	7.	3.44 "	95.20	10.	.74	5.77
11.	19.05	1.40	7.5	3.68 "	102.00	11.	.81	6.35
12.	20.78	1.53	8.	3.93 "	108.80	12.	.88	6.93
13.	22.51	1.66	8.5	4.17 "	115.61	13.	.96	7.51
14.	24.24	1.78	9.	4.42 "	122.41	14.	1.03	8.08
15.	25.97	1.91	9.5	4.66 "	129.21	15.	1.10	8.66
16 or 1 lb.	27.71	2.04	10.	4.91 "	136.01	16.	1.18	9.24
1 lb. 1 oz.	29.44	2.16	10.5	5.15 "	142.81	17.	1.25	9.82
" 2 "	31.17	2.29	11.	5.40 "	149.61	18.	1.32	10.39
" 3 "	32.90	2.42	11.5	5.64 "	156.41	19.	1.40	10.97
" 4 "	34.63	2.55	12.	5.89 "	163.21	20.	1.47	11.55
" 5 "	36.36	2.67	12.5	6.14 "	170.01	21.	1.54	12.13
" 6 "	38.09	2.80	13.	6.38 "	176.81	22.	1.62	12.70
" 7 "	39.82	2.93	13.5	6.63 "	183.61	23.	1.69	13.28
" 8 "	41.56	3.06	14.	6.87 "	190.41	24.	1.76	13.86
" 9 "	43.29	3.18	14.5	7.12 "	197.21	25.	1.84	14.44
" 10 "	45.02	3.31	15.	7.36 "	204.01	26.	1.91	15.01
" 11 "	46.76	3.44	15.5	7 61 "	210.81	27.	1.99	15.59
" 12 "	48.49	3.57	16.	7.85 "	217.61	27.71	2.04	16 or 1 lb.
" 13 "	50.22	3.69	16.5	8.10 "	224.41	29.	2.13	1.05 lb..
" 14 "	51.95	3.82	17.	8.34 "	231.21	30.	2.21	1.08 "
" 15 "	53.68	3.95	17.5	8.59 "	238.01	31.	2.28	1.12 "
2 lb.	55.42	4.07	18.	8.83 "	244.81	32.	2.35	1.15 "
2 lb. 1oz.	57.15	4.20	18.5	9.08 "	251.61	33.	2.43	1.19 "
" 2 "	58.88	4.33	19.	9.33 "	258.41	34.	2.50	1.23 "
" 3 "	60.62	4.46	19.5	9.57 "	265.21	35.	2.57	1.26 "
" 4 "	62.35	4.59	20.	9.82 "	272.01	36.	2.65	1.30 "
" 5 "	64.08	4.71	20.5	10.06 "	278.81	37.	2.72	1 34 "
" 6 "	65.81	4.84	21.	10.31 "	285.61	38.	2.79	1.37 "
" 7 "	67.54	4.97	21.5	10.55 "	292.41	39.	2.87	1.41 "
" 8 "	69.27	5.10	22.	10.80 "	299.21	40.	2.94	1.44 "
" 9 "	71.01	5.22	22.5	11.04 "	306.01	41.	3.01	1.48 "
" 10 "	72.74	5.35	23.	11.29 "	312.81	42.	3.09	1.52 "
" 11 "	74.47	5.48	23.5	11.53 "	319.61	43.	3.16	1.55 "
" 12 "	76.20	5.60	24.	11.78 "	326.41	44.	3.24	1.59 "
" 13 "	77.93	5.73	24.5	12.02 "	333.21	45.	3.31	1.62 "
" 14 "	59.67	5.86	25.	12.27 "	340.02	46.	3.38	1.66 "
" 15 "	81.40	5.99	25.5	12.52 "	346.82	47.	3.46	1.70 "
3 lb.	83.13	6.11	26.	12.76 "	353.62	48.	3.53	1.73 "
" 1oz.	84.86	6.24	26.5	13.01 "	360.42	49.	3.60	1.77 "
" 2 "	86.59	6.37	27.	13.25 "	367.22	50.	3.68	1.80 "
" 3 "	88.33	6.50	27.5	13.50 "	374.02	51.	3.75	1.84 "
" 4 "	90.06	6.62	28.	13.74 "	380.82	52.	3.82	1.88 "
" 5 "	91.79	6.75	28.5	13.99 "	387.62	53.	3.90	1.91 "
" 6 "	93.52	6.88	29.	14.23 "	394.42	54.	3.97	1.95 "
" 7 "	95.65	7.01	29.5	14.48 "	401.22	55.42	4.07	2. lb.
" 8 "	96.98	7.13	30.	14.72 "	408.02			

Table 175

CAPACITY OF PIPES AND CYLINDRICAL TANKS OF VARIOUS DIAMETERS IN GALLONS PER FOOT OF LENGTH

Feet	Inches											
	0	1	2	3	4	5	6	7	8	9	10	11
0	....	.0408	.1632	.3672	.6528	1.020	1.469	1.999	2.611	3.305	4.080	4.937
1	5.875	6.895	8.00	9.18	10.44	11.79	13.22	14.73	16.32	17.99	19.75	21.58
2	23.50	25.50	27.58	29.74	31.99	34.31	36.72	39.21	41.78	44.43	47.16	49.98
3	52.88	55.86	58.92	62.06	65.28	68.58	71.97	75.44	78.99	82.62	86.33	90.13
4	94.00	97.96	102.0	106.1	110.3	114.6	119.0	123.4	128.0	132.6	137.3	142.0
5	146.9	151.8	156.8	161.9	167.1	172.4	177.7	183.2	188.7	194.3	199.9	205.7
6	211.5	217.6	223.4	229.5	235.7	242.0	248.2	254.7	261.1	267.7	274.3	281.1

Table 176

CONVERTING QUANTITIES OF PETROLEUM GIVEN IN METRIC TONS INTO IMPERIAL GALLONS FOR VARIOUS DENSITIES

Specific Gravity	Multiplier	Specific Gravity	Multiplier
0.700	314.946042	0.815	270.505803
0.705	312.712382	0.820	268.856378
0.710	310.510183	0.825	267.226945
0.715	308.338783	0.830	265.617144
0.720	306.197451	0.835	264.026622
0.725	304.095834	0.840	262.455035
0.730	302.003054	0.845	260.902047
0.735	299.948612	0.850	259.367329
0.740	297.921932	0.855	257.850561
0.745	295.922456	0.860	256.351430
0.750	292.616306	0.865	254.869630
0.755	292.002953	0.870	253.404862
0.760	290.081881	0.875	251.956834
0.765	288.185921	0.880	250.525261
0.770	286.314584	0.885	249.109864
0.775	284.467393	0.890	247.710370
0.780	282.643884	0.895	246.326513
0.785	280.843605	0.900	244.958038
0.790	279.066113	0.910	242.266186
0.795	277.310981	0.915	240.942327
0.800	275.577787	0.950	232.065505
0.805	273.866124	1.000	220.46223
0.810	272.175555		

Note—To convert Imperial gallons into metric tons, divide the number of Imperial gallons by the figures given in the second column.

In the above table the metric ton has been taken as being equivalent to 2204.6223 lb. Av.

WATER DATA*

Freezing point at sea level	32	deg. fahr.
Point of greatest density	39.1	deg. fahr.
British standard for specific gravity	62	deg. fahr.
Boiling point at sea level	212	deg. fahr.

32 deg. fahr., weight per cu. ft., 62.418 lb.; cu. in., .03612 lb.

39.1 deg. fahr., weight per cu. ft., 62.425 lb.; cu. in., .036125 lb.

62 deg. fahr., weight per cu. ft., 62.355 lb. ; cu. in., .03608 lb.

212 deg. fahr., weight per cu. ft., 59.760 lb.; cu. in., .03458 lb.

One cu. ft. contains 7.48 U. S. Gallons or 6.232 Imperial Gallons.

One U. S. Gallon contains 231 cu. in. or 0.13368 cu. ft., and weighs 8⅓ lb. at 62 deg. fahr.

One Imperial Gallon contains 277.274 cu. in. or 0.16046 cu. ft., and weighs 10 lb. at 62 deg. fahr.

To convert Imperial Gallons to U. S. Gallons, multiply by 1.2.

To convert U. S. Gallons to Imperial Gallons, multiply by 0.8333.

To convert pounds per square inch, pressure to feet head, multiply by 2.31.

To convert feet head to pounds per square inch pressure, multiply by 0.433.

A Miner's Inch is the quantity of water that will flow in one minute through an opening one inch square in a plank 2 inches thick, under a head of 6½ inches to the center of the orifice. This is approximately 1.2 cu. ft. or 9 U. S. Gallons per minute.

* Courtesy Goulds Mfg. Co.

The mean pressure of the atmosphere is estimated at 14.7 pounds per square inch at sea level; with a perfect vacuum it will sustain a column of mercury 29.9 inches or a column of water 33.9 feet high. At this pressure the practical suction lift for pumping is about 22 feet.

Doubling the diameter increases the capacity of a pipe four times.

To determine the velocity in feet per minute necessary to discharge a given volume of water in a given time, multiply the number of cubic feet of water by 144 and divide the product by the area of the pipe in inches.

To find the theoretical velocity in feet per minute due to any head, multiply the square root of the head in feet by 8.02.

To determine power required for pumping, use formula:

$$\text{Horsepower} = \frac{\text{G. P. M.} \times \text{H.}}{4000 \times \text{E.}}$$

where G. P. M. = gallons of water pumped per minute; H = total lift and force in feet including pipe friction head, and E = the efficiency of the pump expressed as a decimal.

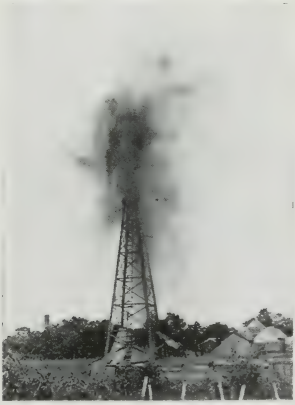


Fig. 166

Table 177

WEIGHT AND SPECIFIC GRAVITIES OF METALS

(Kent)

	Specific Gravity Range according to Several Authorities	Specific Gravity Approx. Mean Value used in Calculation of Weight	Weight per cubic foot, lb.	Weight per cubic inch lb.
Aluminum	2.56 to 2.71	2.67	166.5	0.0963
Antimony	6.66 to 6.86	6.76	421.6	0.2439
Brass: Copper + Zinc				
80 20	7.8 to 8.6	8.60	536.3	0.3103
70 30		8.40	523.8	0.3031
60 40		8.36	521.3	0.3017
50 50		8.20	511.4	0.2959
Bronze: Cop. 95 to 80, Tin 5 to 20	8.52 to 8.96	8.853	552.	0.3195
Calcium	1.58	1.58	98.5	0.0570
Cobalt	8.5 to 8.6	8.55	533.1	0.3085
Gold, pure	19.245 to 19.361	19.258	1200.9	0.6949
Copper	8.69 to 8.92	8.853	552.	0.3195
Iron, Cast	6.85 to 7.48	7.218	450.	0.2604
Iron, Wrought	7.4 to 7.9	7.70	480.	0.2779
Lead	11.07 to 11.44	11.38	709.7	0.4106
Mercury 32 deg.	13.60 to 13.62	13.62	849.3	0.4915
Mercury 60 deg.	13.58	13.58	846.8	0.4900
Mercury 212 deg.	13.37 to 13.38	13.38	834.4	0.4828
Nickel	8.279 to 8.93	8.8	548.7	0.3175
Platinum	20.33 to 22.07	21.5	1347.0	0.7758
Silver	10.474 to 10.511	10.505	655.1	0.3791
Steel	7.69* to 7.932**	7.854	489.6	0.2834
Tin	7.291 to 7.409	7.350	458.3	0.2652
Tungsten	17.00 to 17.6	17.3	1078.7	0.6243
Zinc	6.86 to 7.20	7.00	436.5	0.2526

*Hard and burned. **Very pure and soft. The sp. gr. decreases as the carbon is increased.

FULLER'S RULE FOR OBTAINING THE AMOUNT OF CEMENT, SAND AND GRAVEL OR STONE REQUIRED TO BUILD ONE CUBIC YARD OF CONCRETE

380 lb. cement = one barrel

Let C = Number of parts cement.
Let G = Number of parts of gravel or stone.
Let S = Number of parts sand.
Let P = Number of bbl. of cement for one cu. yd. concrete.

$$\frac{11}{C+S+G} = \text{"P"} \quad \frac{P \times S \times 3.8}{27} = \text{cu. yds. of sand "S."}$$

$$\frac{P \times G \times 3.8}{27} = \text{cu. yds. of stone or gravel "G."}$$

Let unit represent the parts of cement and express other parts correspondingly.

Example:

1 part Cement	= 1
3 parts Sand	= 3
5 parts Gravel or Stone	= 5

$$\frac{11}{1+3+5} = \text{"P"} = 1.22 \quad \frac{1.22 \times 3 \times 3.8}{27} = \text{"S"} = .515$$

$$\frac{1.22 \times 5 \times 3.8}{27} = \text{"G"} = .858$$

Fig. 167

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